Product Engineering

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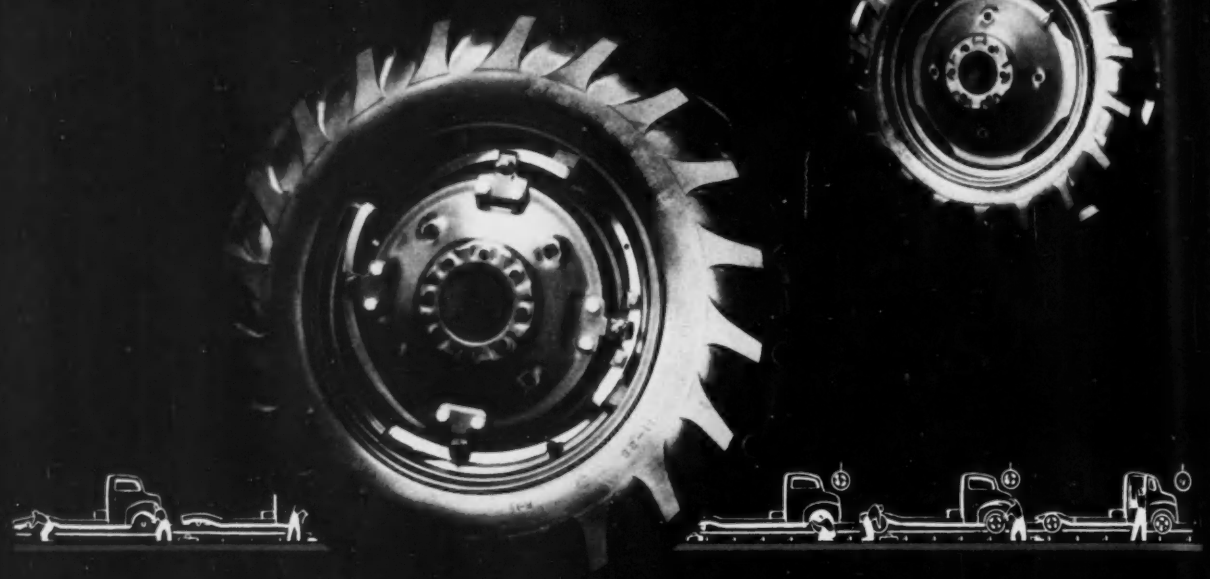
Big wheel in the automotive business...



SHARON* RIM STEEL DECLARED BEST BY LEADING BUILDER OF AUTOMOTIVE WHEELS

We use a lot of wheels here in America. Our cars, trucks, busses, aircraft, farm and construction machinery require hundreds of thousands of wheels annually. Wheels that must be a match for our constantly increasing speeds and weights —wheels that must be tough and durable, exactly round and perfectly balanced.

Mass production is essential to keep the cost of wheel production at a minimum. Today massive wheels are practically squeezed into shape on giant presses at amazing speeds — each one a perfect circle of weight and balance.

To enable wheel builders to produce at high speeds requires the finest rim and wheel steels. Each coil must be of exactly the right analysis, free of blemishes with consistent gauge uniformity.

Leading wheel makers have learned they can trust Sharon to deliver this kind of steel day in and day out — that's why today Sharon is one of the leading producers of strip steel for the continuous production of rims and wheels.

*Specialists in STAINLESS, ALLOY, COLD ROLLED and COATED Strip Steels.

SHARON STEEL CORPORATION

Sharon, Pennsylvania

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For information on Titanium contact Mallory-Sharon Titanium Corp., Niles, Ohio

SHARONSTEEL

VOLUME 23 **Product Engineering** NUMBER 11

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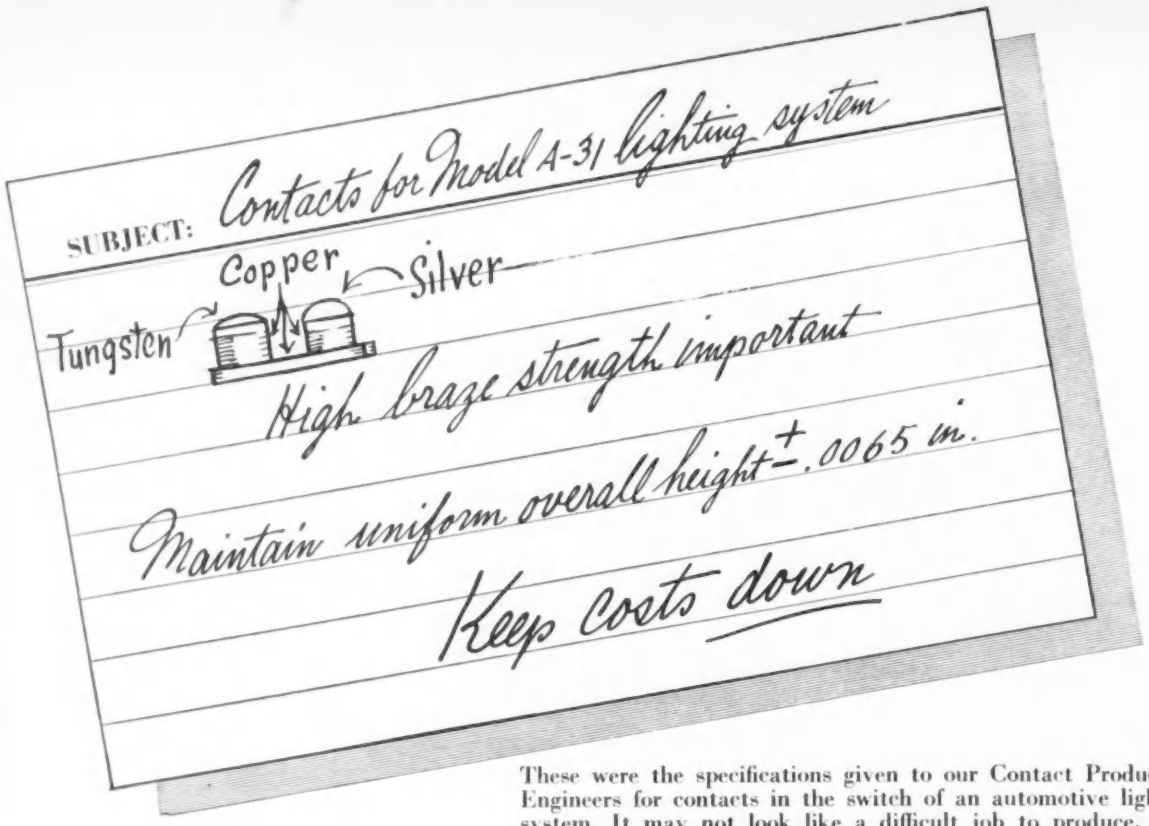
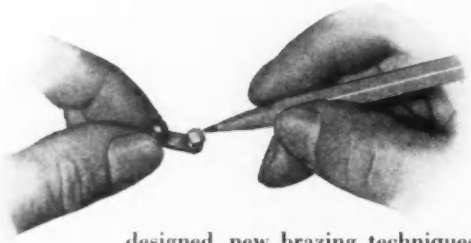


These were the specifications given to our Contact Production Engineers for contacts in the switch of an automotive lighting system. It may not look like a difficult job to produce. But, tungsten is hard and brittle and must be carefully ground to shape. Silver is soft and ductile . . . difficult to machine without "tearing". Brazing materials for silver and tungsten are not the same.



These were just a few of the problems involved in this particular job that were solved by Mallory production techniques. For example: new tungsten grinding equipment was designed, new brazing techniques were developed and the silver contact point was fabricated without machining. As a result, dimensions were held to the specified accuracy . . . the required high braze strength was achieved . . . the entire job was mass produced, uniformly and at low cost.

This is another example of how Mallory contact design and production experience, backed by specialized plant facilities, worked out the answer to a specific problem. Regardless of the requirements of your electrical contacts, Mallory can produce them to the highest quality standards . . . at the right price.

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Highlights

When requesting further information from companies and organizations mentioned in the items below, confusion can be avoided by referring to the issue of Product Engineering in which items appear

METALLIC MATERIALS

TENSILE TESTS conducted at the National Bureau of Standards on pure nickel indicate that the metal yield and tensile strength, as well as the ductility at maximum load, tend to decrease with increase in temperature. Certain irregularities appear in the temperature range of 80 to 300 F.

ALLOYS OF INDIUM with lead, tin, cadmium and bismuth are finding important uses in bearings, solders and as glass wetting materials. Battelle Memorial Institute reports that indium diffused into steel-backed cadmium alloy bearings improves their corrosion resistance without impairing fatigue life. One to two percent indium added to a tin-lead solder improves resistance to alkali corrosion. A 50-50 tin-indium alloy, called Cerroseal 35, is used for glass-to-glass or glass-to-metal seals.

ELEVATED-TEMPERATURE test comparisons made at Lunkenheimer Co., Cincinnati, on cast steel Grades WC4, WC5, WC6 and WC9 as per ASTM Specification A217-49T show WC5 and WC9 (1.0 percent Mo) have similar creep strength characteristics and are superior to WC4 and WC6 (0.5 percent Mo) in this respect.

INTENSIFIED STUDY of titanium-boron steels made by the Cornell Aeronautical Laboratory, with a number of alloy additions showed that steels having a titanium-carbon ratio of two to four were superior to those in which the ratio was higher. Titanium-boron alloys containing two to three chromium and one percent molybdenum have best properties of alloys tested.

EASY METHOD of bonding metals has been announced by the American Silver Co., Flushing, N.Y. Process uses braze-clad metals — a ferrous or non-ferrous metal strip clad with layers of silver brazing alloy. Typical applications are large area, pressure tight, and blind joints.

INGOT IRON has been undergoing low temperature tests at the National Bureau of Standards. Data show that cold working of hot rolled or normalized specimens by extension in tension at room temperature reduced some of the brittleness at low temperatures, while cold working of annealed specimens increased brittleness.

METHODS for eliminating porosity and brittleness caused by hydrogen in steel have been worked out by M. I. T. and O. N. R. personnel. One investigation resulted in an analytical technique that presents an accurate picture of the hydrogen content in steels, while the other study centered around the effects of different hydrogen contents on the mechanical properties of steel.

NONMETALLIC MATERIALS

CONTINUOUS OPERATION of motors at 300 F for 500 to 1,000 hr without lubrication intervals has been forecast by the Office of Naval Research. Recently developed high-temperature silicone-lithium soap greases give satisfactory performance for as much as 6,000 hours.

LIQUID SYNTHETIC RUBBER or resin compound is being applied like a toothpaste ribbon to form gaskets by the Dewey and Almy Chemical Co., Cambridge, Mass. The rubber is forced through a nozzle onto a spinning part to be sealed and then baked. The finished product is a cellular or puffed gasket that keeps out dust and water.

NATURAL PEARLESCENT FINISH for plastics is announced by Bee Chemical Co., Chicago 33, Ill. Expected to find its major application on kitchen appliances, finish will be available in different bases to coat polystyrene, acrylic, acetate and butyrate. It can be applied to surface of colored parts or to reverse side of clear plastics. Decorative finish is said to be similar to a soft, sparkling, metallic finish and particularly attractive in white or light pastel shades.

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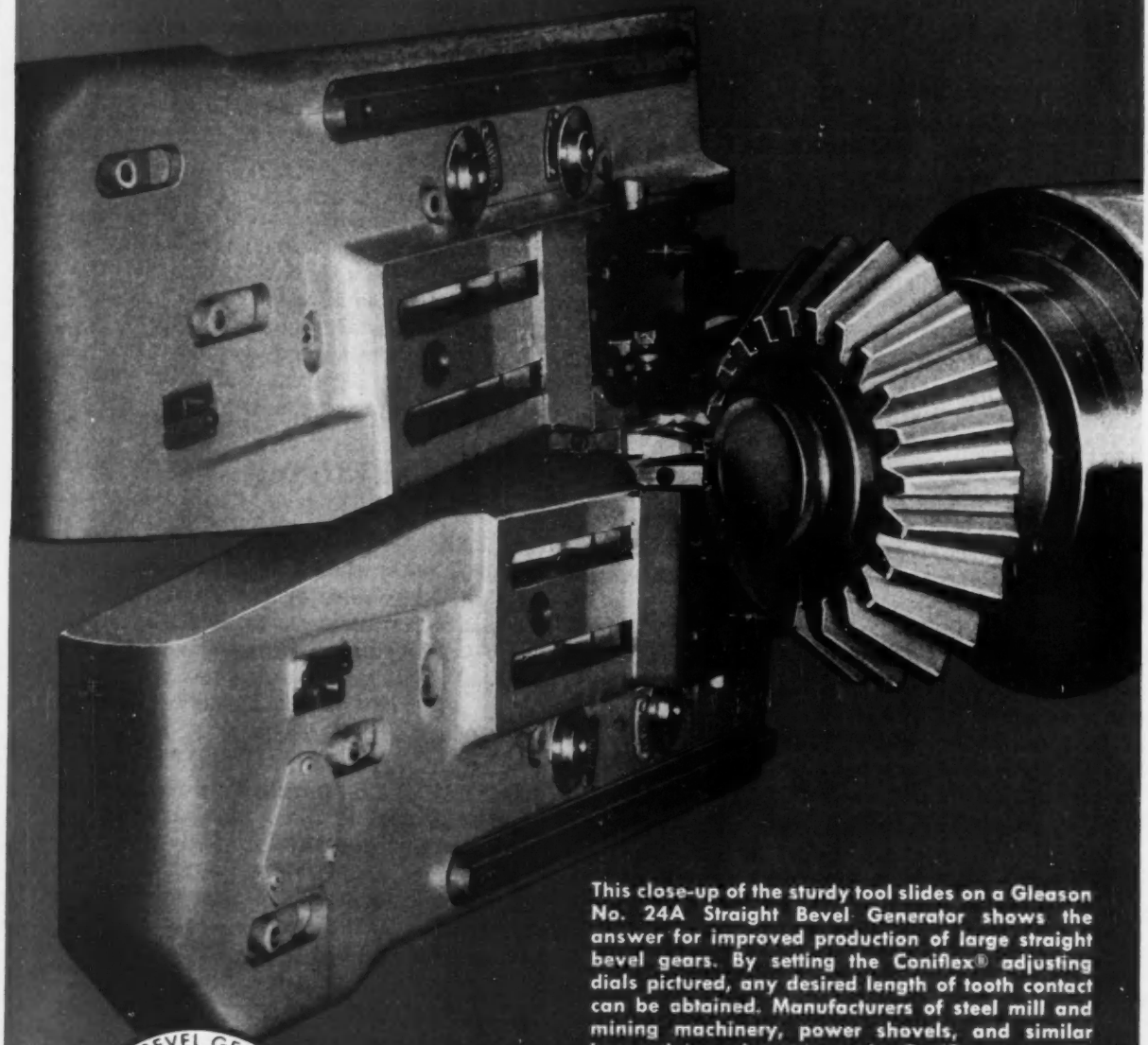
THE ANSWER

FOR BETTER LARGE STRAIGHT BEVEL GEARS



This close-up of the sturdy tool slides on a Gleason No. 24A Straight Bevel Generator shows the answer for improved production of large straight bevel gears. By setting the Coniflex® adjusting dials pictured, any desired length of tooth contact can be obtained. Manufacturers of steel mill and mining machinery, power shovels, and similar heavy-duty equipment are using Coniflex gears, with tooth contact suited for the application, for easier assembly, smoother operation, and longer life.

Send us details of your large straight bevel gear applications. We will gladly show you how Coniflex gears, cut on the No. 24A, will improve your results.

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RECENT LABORATORY TESTS conducted at the National Bureau of Standards demonstrate that certain ceramic coatings will prevent carbon absorption by aircraft exhaust systems made of stainless steel. Bureau recommends service testing of coated exhaust parts to establish the relative merits of the ceramics coatings.

TOUGH electrical insulating material for use in heavy-duty equipment has been tradenamed Aboglas by the Natvar Corp., Woodbridge, N. J. Product consists of a layer of varnish-saturated asbestos paper sandwiched and bonded between two layers of varnished open-weave Fiberglas.

ANTI-SEIZE LUBRICANT for use wherever extreme pressures are encountered has been released by the Bel-Ray Co., Inc., Madison, N.J. The molybdenum disulfide compound is claimed to be stable and non-melting and to prevent seizing and galling at pressure of 100,000 lb/sq inch.

PROCESSES

"SPARK" PIERCING of the holes in a diamond wire-drawing die is described in the August issue of Metal Industry (London). Diamond is immersed in a salt solution with one electrode attached to it, while the second electrode is dropped into the solution. Sparks in this closed electric circuit permit rapid formation of the hole.

CONDENSER-DISCHARGE TECHNIQUE perfected by workers at the Naval Ordnance Laboratory, White Oak, Md., now makes it possible to butt weld very thin stainless steel. The job is accomplished through electrical energy stored in a bank of capacitors which is discharged through transformers into the weld.

FLASH WELDING of titanium, according to American Welding and Mfg. Co., Warren, Ohio, can be successful, provided cross sections of two or more inches are involved. Properties of the weld approach those of the parent metal when welds are produced on conventional machines.

IMPREGNATION OF CASTINGS with a mixture of sodium-silicate and 500 mesh metallic flour has been announced by the Sealmore Corp. of Muskegan, Mich. The treated castings will withstand pressures of 9,000 psi for 2 1/2 hours. Temperature of 2,000 F liquifies impregnant.

LOW-TEMPERATURE FLAME PLATING developed by the Linde Air Products Co., N.Y.C ., applies an undiluted deposit of tungsten carbide, in powdered form, on almost any base metal. Temperature of the base metal does not exceed 400 F during the plating operation, reducing to a minimum any change in properties of base metal.

HARD CHROME PLATING has been applied to aluminum alloy parts, such as engine cylinders, pistons and brake drums to reduce wear. Plating is put directly on the aluminum surface, according to Metal Industry (London), rather than on intermediate layer of copper, iron or nickel. Though the chrome plate may crack under heat, this network of fine fissures resists peeling.

ELECTROLYTIC GRINDER for the sharpening of hard tools has been announced by the Super-cut Corp., Chicago, Illinois. The metal grinding wheel is charged negatively, the work piece positively. An electrolytic chemical is squirted over the grinding surface. Small particles of metal flow from the work piece, through the chemical and onto the wheel, thus sharpening the tool. A pinch of bort on wheel speeds process.

COMPONENTS

FASTENER INSERTS for sandwich type aircraft panels will be available in the near future, according to Sta-fast, Inc., Burbank, Calif. The insert is positioned in a bored hole and bonded with Epon VI, a metal bonding material developed by the Shell Chemical Corp. Tests indicate panel will collapse before fastener fails.

MINIATURE AIR CONDITIONER developed by the Duco Machine and Tool Co., Brooklyn, N.Y., is being used to prevent fogging, freezing and dirt infiltration in aircraft gun sights. Wide commercial use for the unit is forecast for business equipment located in the tropics and in storage areas where humidity must be controlled.

ENGINE MUFFLER designed for high-compression engines is being distributed by the Maremont Automotive Products Inc., Chicago, Ill. The four-ply asbestos-wrapped assembly is available with three steel plys spun together and interlocked with end caps. The asbestos wrapping is totally enclosed for increased protection.

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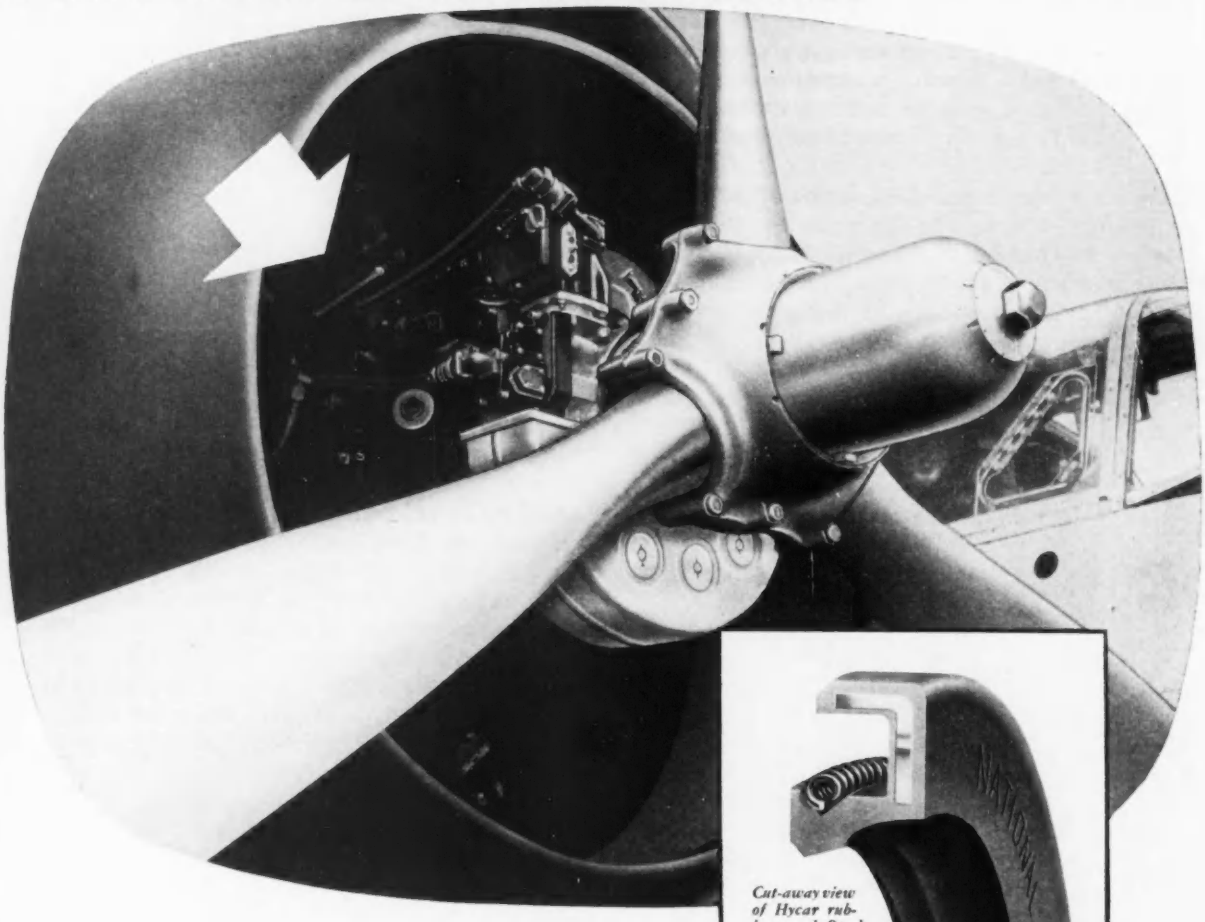
Another new development using

B. F. Goodrich Chemical *raw materials*



Cut-away view of Hycar rubber seal. Seal has 6½" i.d., molded onto metal base, is spring-tensioned, precision-trimmed.

NO OIL LEAKS HERE

—because of HYCAR!

Oil seals designed and manufactured by National Motor Bearing Co., Inc., Redwood City, Calif., for Hamilton Standard Division, Windsor Locks, Conn. B.F.Goodrich Chemical Co. supplies the Hycar rubber only.

PREVENTING leakage from propeller oil control assemblies is a vital job—calls for a seal with unique advantages. The seal must be positive, must resist the deteriorating effects of oil, extreme temperatures and high surface speeds.

It was only natural that the seal manufacturer chose Hycar nitrile rubber—for Hycar meets these rigid requirements.

The Hycar rubber seals are precision-molded and compact in design because of critical space limitations. They operate in temperatures ranging from −65°F. to 220°F. And they withstand the severe abrasion conditions resulting from surface speeds of 3,250 f.p.m.

These Hycar rubber seals are suitable for use with AN-O-8 Grade 1100 and AN-O-9 Grade 1010 fluids, and MIL-O-5606 oil.

Perhaps one of the many Hycar rubber compounds can solve a problem for you—can help you improve or develop a sales-making product. For Hycar resists oil, gas, heat and cold, aging, abrasion and many chemicals. For helpful technical information, please write Dept. **HP-6**, B. F. Goodrich Chemical Company, Rose Building, Cleveland 15, Ohio. Cable address: Goodchemco. In Canada: Kitchener, Ontario.

B. F. Goodrich Chemical Company
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Hycar American Rubber

GEON polyvinyl materials • HYCAR American rubber • GOOD-RITE chemicals and plasticizers • HARMON organic colors

PREVENTION OF CAVITATION in engine-driven hydraulic pumps by compressing air in the oil tank has been developed by the Romec Division of Lear, Inc. Cavitation kit consists of a 30 cu in. silica gel dehydrator and an air compressor. The automatic rig starts pumping at 7 to 8 psi and stops when tank pressure is 9.75 psi. Unit delivers 100 cu in./min of air at 35,000 feet.

FLUID-PISTON-TYPE BEARING that can be made from any material and lubricated with any fluid has been developed by Allis-Chalmers. Designed primarily for application in pumps that must be lubricated by the liquid being handled, bearings can be used for radial or thrust loads.

HIGH-PRESSURE stainless steel bellows are being produced by the Clifford Mfg. Co., Waltham, Mass. Developed for equipment that was limited in operation because of lack of suitable units, new bellows are rated at 3,600 lb/sq inch.

TESTING

HIGH-FIDELITY TAPE RECORDER sensitive to signal frequencies between 200 and 100,000 cps has been developed by the Ampex Electric Co., Redwood City, Calif. Unit can record high-frequency flutter, vibration or transient phenomena previously obtained with cathode-ray oscilloscope and moving picture camera.

CONTROL OF MOISTURE CONTENT is being handled at the Langley Field, Va. NACA wind tunnel by a General Electric dewpoint recorder. Instrument is claimed to monitor the moisture content to an accuracy of five deg at -90 F.

MOTION PICTURES can be taken in the dark on Eastman's new 16 or 35 mm film that is sensitive to infra-red rays. Originally intended for use in spectrographic laboratories, it is being used for high-speed photography of the flow and action of molten metal.

EXTENSOMETER releases itself automatically from test specimen before breaking point is reached and without stopping test. According to Battelle Memorial Institute engineers, this feature is particularly useful in high temperature testing. Automatic release not only protects the extensometer, but also the supplementary indicating and recording mechanisms.

DIGITAL PLOTTER, developed by the Logistics Research Co., Redondo Beach, Calif., charts a graph of one variable against another in response to electrical impulses. Equipment permits simultaneous movement in 1/64-in. steps along the X and Y axes at rates up to 20 steps per second.

CHARPY TESTS made at the Watervliet Arsenal indicate that the reporting of impact values to more than one place after the decimal is not necessary. The method of machining the test notch has no influence on test results if the specimens meet the specifications on the drawing.

FIRST MASS PRODUCED electronic digital computer has been announced by Electronic Computer Corp., New York City. Computer consists of three units, an office desk at which operator sits, metal drum memory unit shaped like a water cooler, and computer proper which is housed in five steel cabinets. It can solve a ten-digit problem in three milliseconds.

THIS MONTH'S COVER

The development of the new V. P. Edison Voicewriter, pictured on this month's cover, demonstrates how a market research group can work hand-in-hand with product designers. Faced with increasing buyers resistance in the business machine market, Thomas A. Edison Incorporated, decided to search out new markets and design a machine specifically for these new customers. Before engineers held their first planning meeting, the Market Research Department spent two years determining that there was a market for a portable dictating machine and what features potential customers wanted. Engineers then developed the "Veep" to fit these specifications. As a final step, Edison called in industrial designer Carl Otto to style the finished product and increase its sales appeal. For the design details of this dictating machine, see page 158. *—Kodachrome McGraw-Hill Studios.*

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An electrolytic process operated at room temperature that enables the following to be done

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2. Clean and renew rusty mechanisms without disassembly or harm to tolerances, delicate components, or non-ferrous metals.
3. Clean and pickle all types of steel, cast iron and malleable iron for finishing operations.
4. Reduce costs on heat treated, forged, or cast parts by descaling prior to subsequent machining or processing.
5. Replace shot or sandblasting for scale removal.
6. Clean and brighten automotive and airplane parts.
7. Salvage iron and steel parts rusted by fire or flood.
8. Remove oil quenching scale and smut electrolytically in bulk.

Write for bulletin describing the many features of this new Alkaline Derusting Process.

METAL FINISHING PROCESSES

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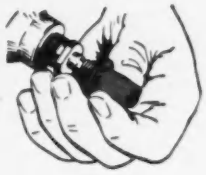
ELECTROPLATING CHEMICALS

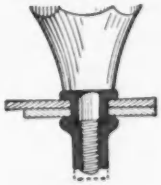
B. F. Goodrich RIVNUTS give new way to fasten leveling feet . . . cut costs!

Rivnuts provide at least 6 clean threads in one simple operation!



1 Rivnut is threaded onto pull-up stud of a manual or pneumatic heading tool.

2 Rivnut is inserted—head firmly against work—tool at right angles to work.



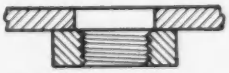
3 Tool lever operates pull-up stud, forming a bulge in the Rivnut shank.

4 After upset, Rivnut threads are still clean and intact, ready for screw attachment.

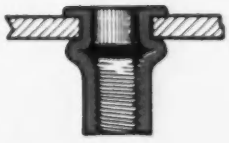
Compare these 4 methods of putting screw threads in thin sheet metal

Tapped—2 threads

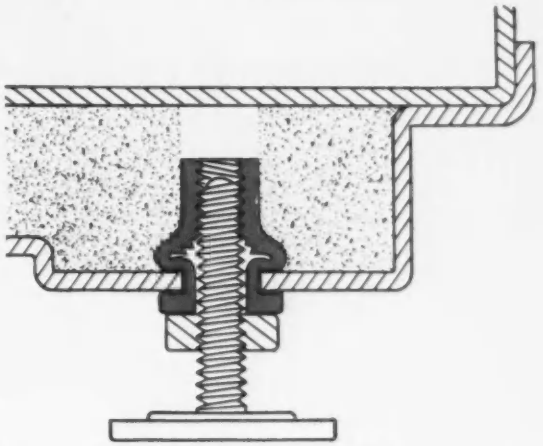
Pierced and tapped—3 threads



Projection welded—4 threads



Rivnut—at least 6 threads



APPLIANCE DESIGNERS were looking for a way to fasten leveling feet to the bottoms of refrigerators, stoves and automatic washers. The metal was too thin to tap, and welding would warp it. Besides, the threads would be ruined in the enameling process.

All these problems were solved by a B. F. Goodrich Rivnut—the *only* one-piece blind rivet with threads! Working from one side of the cabinet, one man installs the Rivnut in a few seconds. The easy-to-use power heading tool forms a bulge in the Rivnut shank—a "second head" that tightly grips the material. At least six threads remain clean to take the leveling-foot screw—more than enough to take the heavy loads. Installation is made *after* enameling without marring the finish.

Besides these advantages, the quick, simple installation of Rivnuts saves time, cuts assembly costs. For help on your fastening problem, write The B. F. Goodrich Company, Dept. PE-112, Akron, Ohio.

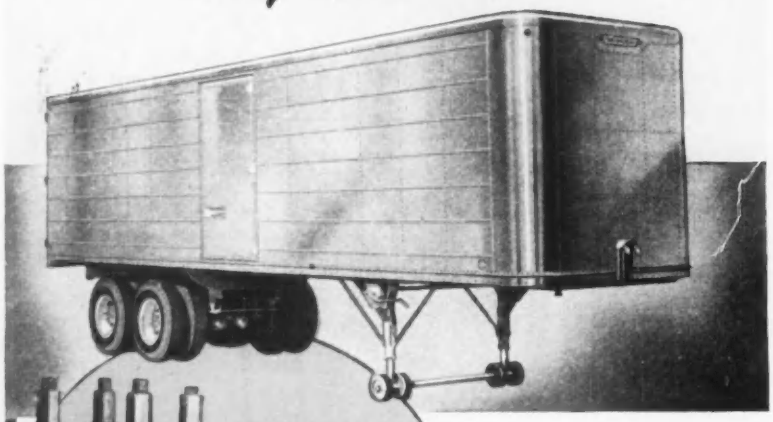
SEND NOW FOR FREE RIVNUT DEMONSTRATOR

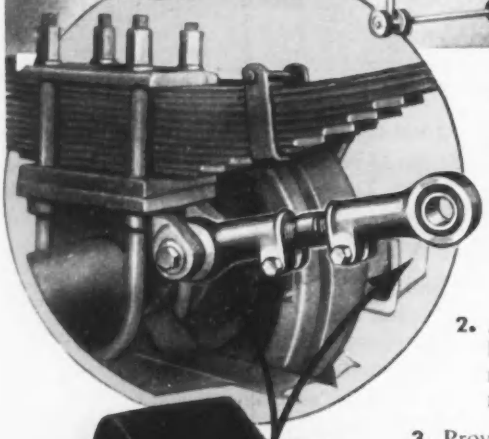
Demonstrates with motion how you can use Rivnuts to fasten TO *and* fasten WITH. Explains construction, gives proved applications . . . Write for your free copy today to the B. F. Goodrich Company, Department PE-112, Akron, Ohio.

B.F.Goodrich RIVNUT *The only one-piece blind rivet with threads*

TRAILMOBILE

RADIUS ROD JOINTS *by* LORD

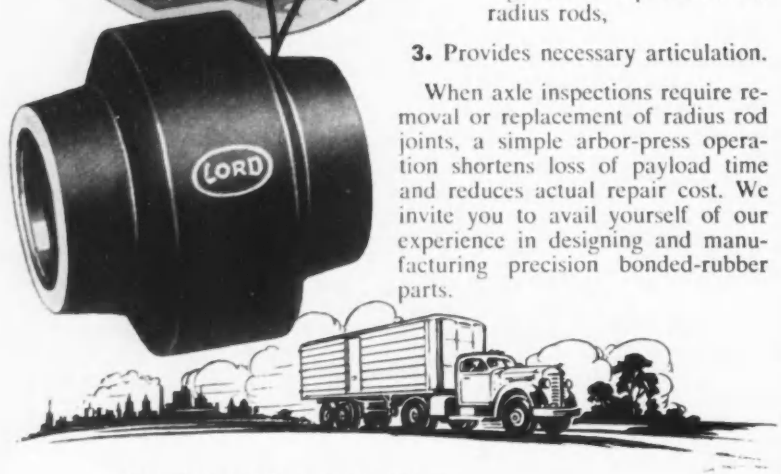




Look at the Trailmobile radius rod joint shown in close-up at the left. This Lord high performance center-bonded-rubber joint .....

1. Saves manufacturing and maintenance cost,
2. Absorbs the shocks of braking-loads and road irregularities imposed on the radius rods,
3. Provides necessary articulation.

When axle inspections require removal or replacement of radius rod joints, a simple arbor-press operation shortens loss of payload time and reduces actual repair cost. We invite you to avail yourself of our experience in designing and manufacturing precision bonded-rubber parts.



20th NATIONAL EXPOSITION of POWER and MECHANICAL ENGINEERING GRAND CENTRAL PALACE, N. Y., BOOTH No. 558 DECEMBER 1-6 1952

LORD MANUFACTURING COMPANY • ERIE, PA.

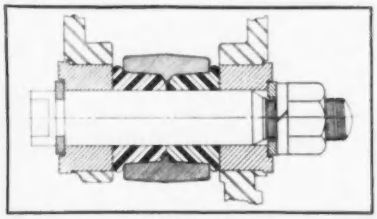
LORD BONDED RUBBER

Headquarters for **VIBRATION CONTROL**

ADVERTISEMENT

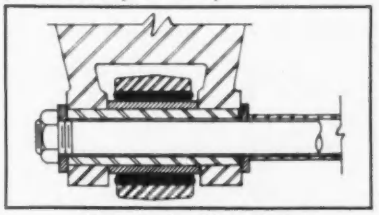
Lord Bonded Rubber Improves Radius Rod Joint on Trailmobile

Trailmobile, Inc. at Cincinnati, Ohio, believed that maintenance costs on their suspension systems could be reduced by redesign of the radius rod rubber bushings. When their standard radius rod had to be disconnected for maintenance of the suspension, often it was necessary to replace a number of parts of the radius rod rubber bushing assemblies.



Old Design

Lord engineers worked with the designers at Trailmobile to arrive at a rubber joint design that permits making an almost limitless number of disconnections of the radius rods without requiring replacements of the rubber joints, requiring only the time needed to remove the pin through the joint and bracket. The Lord Center-Bonded Joint, now standard in new Trailmobile assemblies, not only fully satisfied requirements, but did so with fewer and simpler parts, *and* at a cost lower than that of the unbonded rubber joint used previously.



Lord Design Now Used

Now when it becomes necessary to remove the Trailmobile Radius Rod it is a simple, easy operation to drive the pin from the hanger. When new bushings are necessary the old ones are pressed out and new ones installed with an arbor press.

Improvements of this nature are being designed into a wide diversity of automotive and industrial products as the result of cooperative efforts of Lord Engineers and the Design Engineers of such product manufacturers. Precision manufacture is the added ingredient which gives Lord Engineering its high value to industrial designers.

ADVERTISEMENT

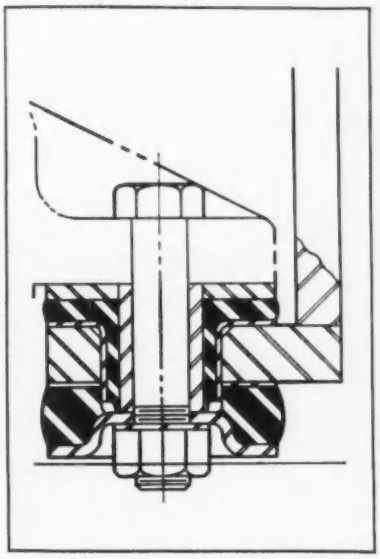
Lord Mountings Cut Service Costs on Ready-Power Units Used by Industry

The most efficient mounting system for Ready-Power "Live Power" units necessitates the isolation of engine vibration, the accommodation of frame twist and absorption of shock loads encountered in industrial materials handling.

Because of limited space the mountings must be sufficiently rigid to prevent excessive engine-generator motion yet flexible enough to isolate engine vibration and absorb shock loads which seriously damage engine brackets, oil lines and other component parts. These shock loads are caused when industrial trucks bump into pallets or solidly packed storage areas or are operated over unusually rough and bumpy surfaces.

The Lord mountings are designed to meet these requirements.

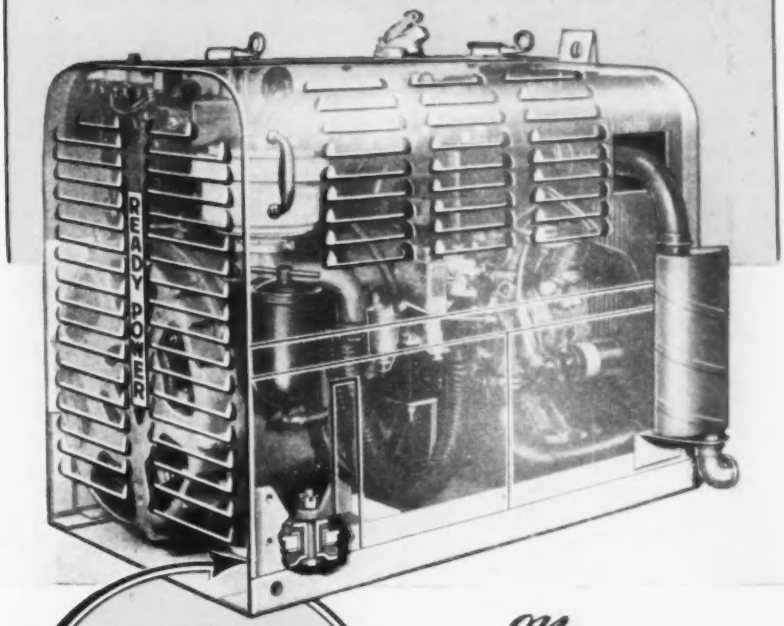
Dupont Neoprene is used as the base in the compound specifically designed by Lord to meet the deteriorating effects of oil, gasoline, etc.



This Lord mounting is designed for easy installation, no extremely close tolerances being involved. The Ready-Power representatives maintain close contact with their equipment under all operating conditions. They report that the use of Lord mountings minimizes maintenance and service formerly the result of shock and vibration.

Further details on this and other successful handling of vibration and shock problems are available on request from Lord Manufacturing Company, Erie, Pa.

LORD MOUNTINGS
SERVE DUAL PURPOSE

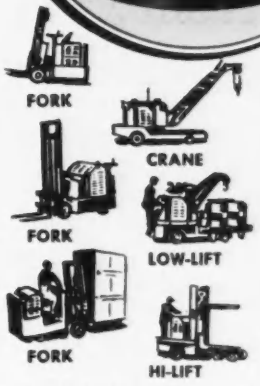


on

THE READY-POWER CO.

"Live Power Units"

LORD Shock Mountings accomplish two vital objectives in the delivery of "Live Power" generated as needed directly on the truck chassis of industrial fork trucks, tractors, cranes and locomotives by Ready Power Units.



1. The upper Lord Mounting J-4497-2 absorbs the unusually high "g" shock loads encountered in industrial lift truck service . . . At the same time it is rigid enough to prevent excessive engine motion due to these destructive shock loads.

2. The lower member J-4591-1 is a rebound snubbing washer thicker than the sandwich section of the upper member J-4497-2. Precompression thus allows variable bracket thickness of plus or minus 1/16 inch. Thus the Lord Mountings serve the dual purpose of minimizing the vibration and the multiple shocks to which Ready-Power units are subjected in powering the heavy tools of industry. You can profit by Lord experience in the control of vibration and shock. Write or call . . .

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LORD — BONDED RUBBER

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Perspectives ~ DESIGN AND DEVELOPMENT

MATERIALS EVALUATION

In the national emergency that has existed since the instigation of the Korean and the cold wars, great emphasis has been placed upon the conservation of critical materials and the search for more available substitutes. In many cases substitution has been costly, not only where the substitute material has failed to perform satisfactorily but also where long and expensive test programs were required to prove the suitability of the substitute. This testing and evaluation of materials has usually been performed on an individual company basis with similar programs being conducted simultaneously.

The aircraft industry has taken an important step to remedy much of this testing and research duplication through the efforts of the Aircraft Industries Association (AIA). The organization was originally formed to represent manufacturers in their relations with the government and military agencies and to handle problems common to the various companies. It has recently become very active in instituting programs of cooperative research and standardization.

The problems involved in this industry are not only those of materials substitution but to an even greater extent those of new materials development and the establishment of new or improved methods of testing.

With the ever-increasing altitudes and speeds for which aircraft are being designed to operate, there are involved the problems of wider temperature limits, higher loads and reduced airframe space. These greatly affect materials used in structures and installations.

AIRCRAFT INDUSTRY PROGRAM

The Aircraft Research and Testing Committee was formed by the AIA to carry out a program of cooperation among the various aircraft companies. The primary objectives of this committee are:

(1) Dissemination and exchange of information.

(2) Development of materials and processes specifications and recommended practices.

(3) Development of industry recommendations for non-industry sources.

Representatives of the various member companies in the AIA get together and develop plans for getting the most out of each for the benefit of all. For instance, in the work being done on the evaluation of boron steels for aircraft applications, the various phases of research and testing are allotted to those member companies who have the greatest "know-how" or the best facilities for carrying out the work in each particular phase.

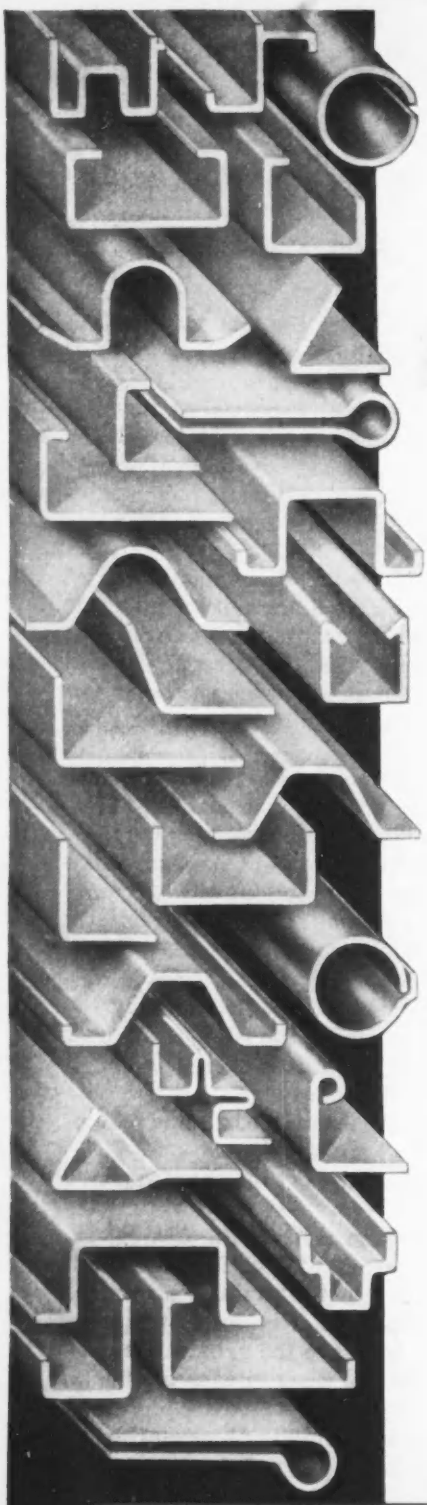
Attention of this committee has been centered mainly on research and testing associated with airplanes and helicopters but great effort is now being directed to missile problems.

PROJECTS STUDIED

Some of the projects, in addition to the boron steel program mentioned above, that have been or are now being studied and evaluated by the committee include: requirements for new transparent plastic; sandwich materials; metal-to-metal adhesives; integrally stiffened sheets: titanium and other materials

The encouraging result of the combined efforts of the aircraft com-

(*continued on page* 117)



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Save Time and Money For Volume Producers

Basic structural parts or parts for decorative or functional trim can be quickly and economically roll-formed for your products by Reynolds Parts Division. Many hundreds of standard roll-formed shapes are available without tooling cost thanks to Reynolds tremendous tooling investment. Tooling for special shapes can also be supplied by Reynolds or work can be produced from your rolls on Reynolds roll-form equipment.

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Whether you make bicycles or baby carriages, metal furniture or fences, television antennae or trucks, window sections or washing machines . . . these and thousands of other products can be produced faster and cheaper in volume by using roll-formed aluminum shapes from Reynolds. For additional information, write for catalog or call the Reynolds office listed under "Aluminum" in your classified telephone directory.
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One of the country's most complete facilities for aluminum fabricating includes:

- **Over 100 mechanical presses ranging from 2 to 1700 tons.**
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- **Equipment for shearing, blanking, forming, riveting and welding, roll-forming, finishing and assembly.**

These facilities can assure a steady flow of blanks or fabricated parts to your specifications and production requirements.

REYNOLDS ALUMINUM FABRICATING SERVICE

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panies give evidence to the importance and value of this type of industry cooperation - particularly in time of national defense.

STANDARDIZATION OF PARTS

Another important project instituted by the AIA has been the development of standards for aircraft engine and propeller utility parts through cooperation of the Air Force, Navy and industry.

This Air Force-Navy-Industry program (ANI), with the help of the Society of Automotive Engineer's Committee E-25, has resulted in the replacement of thousands of individual company manufactured parts with relatively few ANI standard designs. This has substantially reduced the variety of airplane engine and propeller parts and the quantities of these items used each year.

Builders and buyers of powerplants and propellers for military aircraft will use some 78 million fewer "hardware" parts in 1952 as a result of the ANI standards program.

INCREASED EFFICIENCY

This large reduction in small parts inventory has greatly increased manufacturing efficiency and has simplified the procurement of "spares" or replacement parts by the military services. The overall effect of standardization has lowered the cost of aircraft being supplied to the Air Force and Navy.

Because of industry-wide usage, standard hardware items are produced in greater volume than company parts. This has lowered the unit cost of these items. Typical engine bolts and nuts, costing $2.63 each prior to standardization, are now manufactured for one dollar. The quantity usage during this year will up the savings to an estimated million dollars, which is good news to the taxpayer as well as to the aircraft industry.

Other savings accruing indirectly from this standardization include reduction in manhours in engine and propeller production; reduction of company designs and specifications; reclamation of valuable factory space.

In the last few years this group completed 251 designs resulting in the standardization of 19,410 hardware parts prevously stocked under the specification of twelve different companies. This year over 29 million parts manufactured under these ANI standards will be produced for the aircraft engine and propeller program.

THE ANI PROGRAM

The ANI program is based upon the following considerations:

(1) A continuing, well-coordinated and technically sound standardization program, jointly subscribed to by industry and the military services is vital to national defense.

(2) Certain qualities are essential in aircraft engine and propeller parts that are not required in parts for other defense items.

(3) Standardized engine and propeller parts should contain all the essential design, material and process features of the company parts they replace - and must also be easily produced, stocked and maintained.

(4) The technical and administrative "know how" of the aircraft engine and propeller industry is essential to such a program.

The efforts of these programs have contributed greatly to the progress being made in aircraft design and production. The seventh quarterly report to the President by the Director of Defense Mobilization shows that aircraft deliveries have more than tripled since the Korean invasion. Deliveries of aircraft in July reached a level of substantially over 800 per month. The output of jet engines has been rising more rapidly than the production of aircraft, reflecting in part the shift from piston to jet propulsion. Two of the principal engine producers are currently turning out engines at the combined rate of approximately 60 a day, compared to a total of 17 a day 2 years ago.

Magic Chef PROVES . . .

"It's no trick at all"

. . . to find New Savings with SPEED NUTS!

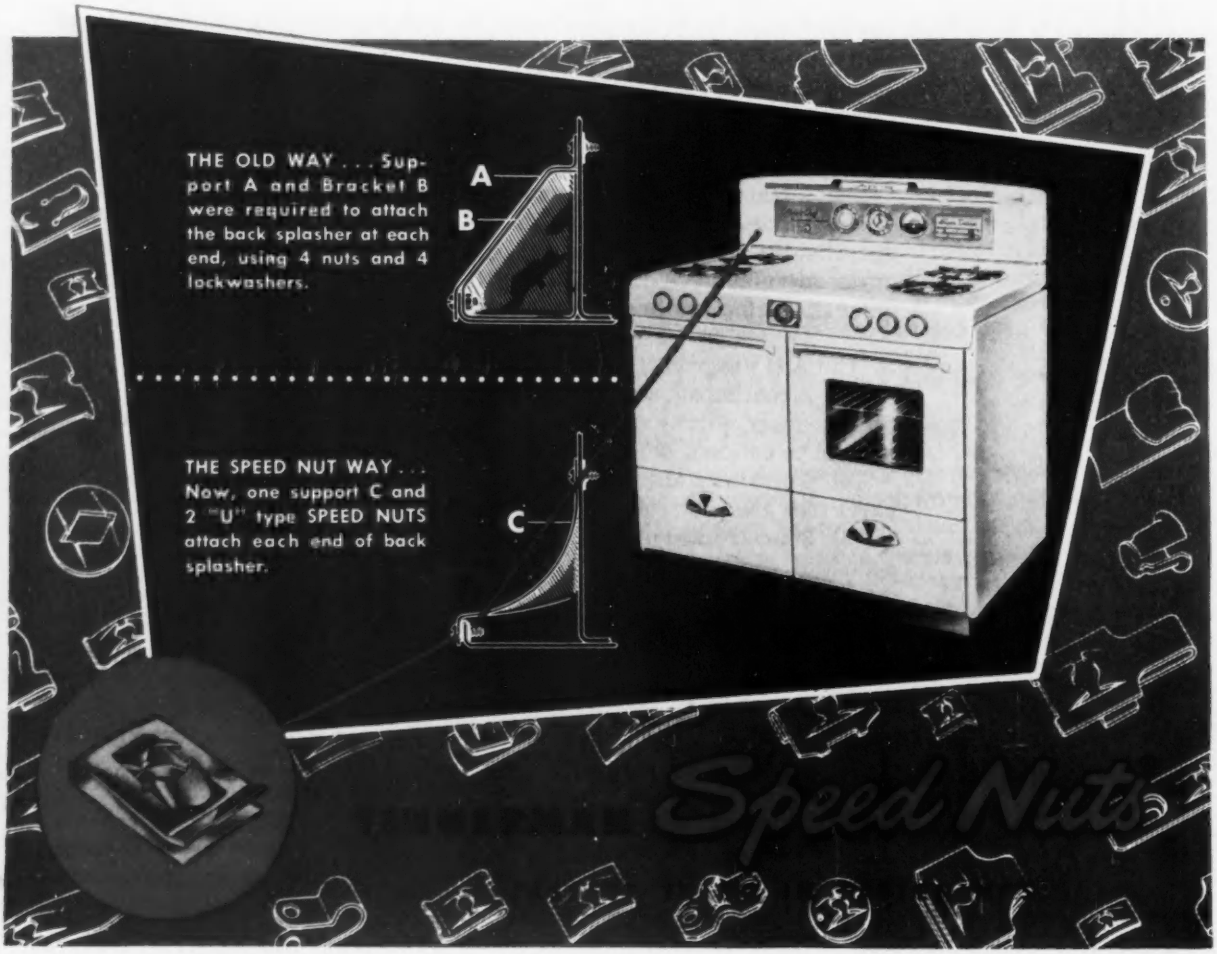
Magic Chef, Incorporated, St. Louis, Missouri, veteran user of SPEED NUTS, adds still another Savings Story to a long list!

Magic Chef engineers and designers have come to rely on assembly and material savings through the use of Tinnerman SPEED NUTS. That's why they again turned to Tinnerman when looking for better fastening methods for the back splasher assembly on a new line of ranges. The result—a neat 22% savings—sold them more than ever on the SPEED NUT economy factor.

Formerly, the back splasher was held in place with two-piece support brackets, threaded nuts and lockwashers. Now, the SPEED NUT WAY, simplified one-piece brackets and "U" type SPEED NUTS do the job better, faster and at less cost! "U" type SPEED NUTS are self-retaining, one-piece, self-locking fasteners that snap quickly and easily in place on the panel in screw-receiving position. They tighten down without being held...eliminate lockwashers ... reduce materials handling to a minimum.

No matter what you manufacture, turn to Tinnerman for fastening efficiency and economy. The Tinnerman representative in your area is ready to assist you. Call him in, he can arrange a FREE FASTENING ANALYSIS of your product to iron out your fastening problems. Contact him today! Or write direct to: Tinnerman Products, Inc., Dept. 12, Box 6688, Cleveland 1, Ohio.

In Canada: Dominion Fasteners Ltd., Hamilton, Ontario. *In Great Britain.* Simmonds Aerocessories, Ltd., Treforest, Wales. *In France* Aerocessoires Simmonds, S.A.—7 rue Henry Barbusse, Levallois (Seine.)


THE OLD WAY . . . Support A and Bracket B were required to attach the back splasher at each end, using 4 nuts and 4 lockwashers.
A
B
THE SPEED NUT WAY . . . Now, one support C and 2 "U" type SPEED NUTS attach each end of back splasher.
C
Speed Nuts

The Will to Win

"He was licked before he started", tersely describes the mental attitude of the defeatist. He thought he couldn't win the contest. Although he put on a good show, the spectators knew almost from the start that he would be the loser. As a man thinketh, so is he. If he thinks he is going to be licked, so is he.

Exactly how the human mind affects the success or failure of the outcome of a man's undertaking will probably never be known. But it is well established that the mental attitude is more than half the battle. This fact has been demonstrated in football, in prize fights, in wrestling and on battle fields. It is also seen in the creative efforts of individuals. Alexander Graham Bell, Robert Fulton, Cyrus McCormick, Morse and a host of others have proved it to be true in the realm of science and invention. Blindness did not prevent Milton from finishing "Paradise Lost", because he "knew" he would complete it. No thought of failure occurred to him.

All of these were men of determination and vision who charted for themselves a course and a goal. They made history; they are history. They won in spite of seemingly unsurmountable obstacles because they possessed that important ingredient in the formula for success: The will to win. They could not even imagine failure.

The man of unswerving determination, whose mind is set on winning, looks upon successive failures as milestones on the road to victory. He sees in each disappointing attempt not failure but new light and guidance. Every fruitless attempt goads him to strive onward again and with ever increased zeal.

In the last two verses of his poem "Alumnus Football", Grantland Rice talks to the college graduate who has just been launched on his business career:

"You'll find the road is long and rough, with soft spots far apart,
Where only those can make the grade who have the Uphill Heart.
And when they stop you with a thud or halt you with a crack,
Let Courage call the signals as you keep on coming back.

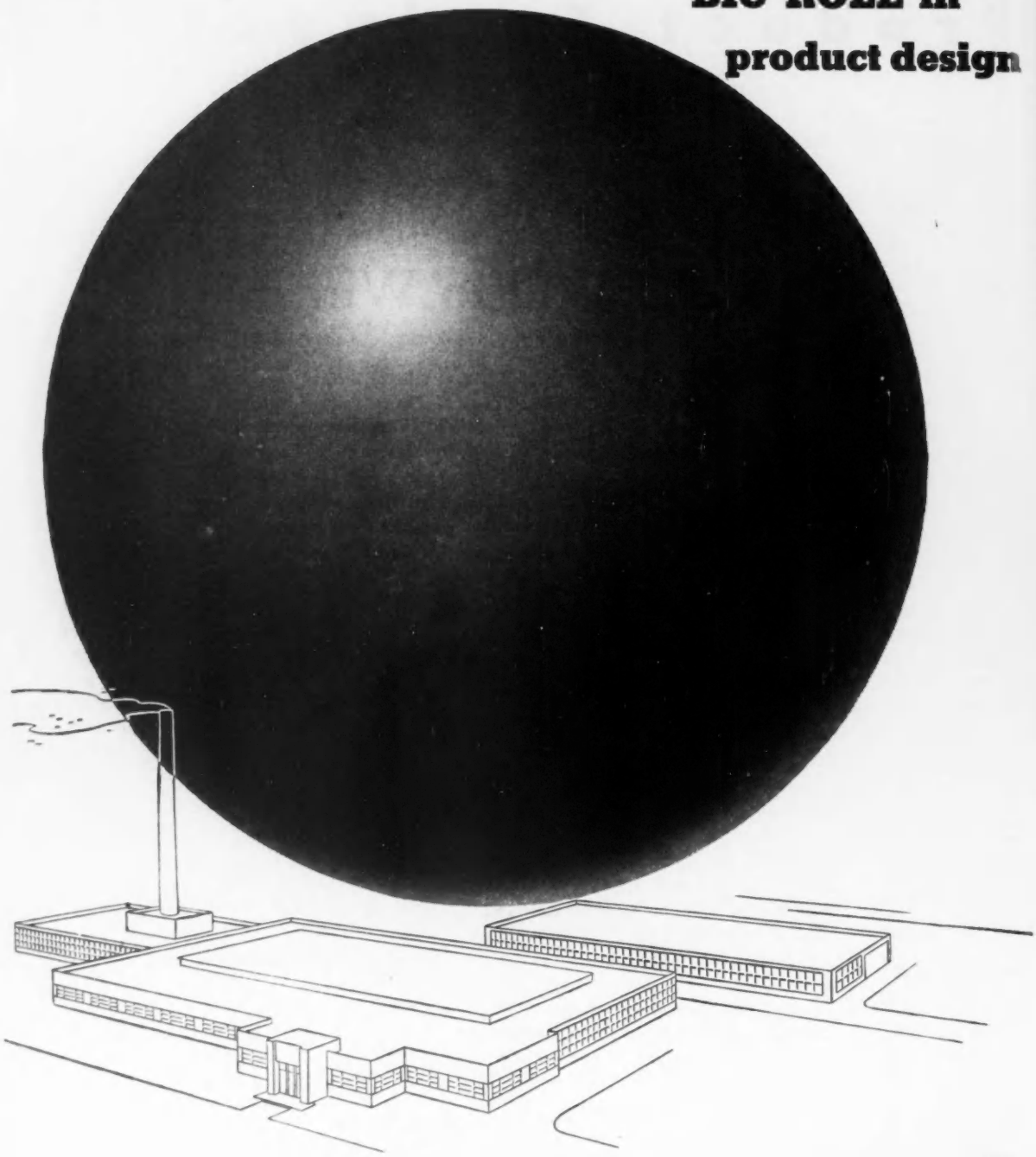
"Keep coming back, and though the world may romp across your spine,
Let every game's end find you still upon the battling line;
For when the One Great Scorer comes to mark against your name,
He writes—not that you won or lost—but how you played the Game."

Last two stanzas of the poem "Alumnus Football" by Grantland Rice. Published with permission of the author.

Every successful product design is but the culmination of calculations and recalculations; trials, tests and failures; ideas worked upon and discarded; repeated layouts, details and assemblies until finally there emerges the new model, the wonderful new machine, the great new product. To the engineers who created it, it is nothing to get excited over. They "knew" from the beginning that they would win. Without the will to win the great creation would have died aborning.

George F. Zodenhoft

BIG ROLE in product design



Simplifying product design is a job in which New Departure Ball Bearings excel. N-D-Seal Bearings, for example, often require less housing space and eliminate various fittings and parts . . . make possible smooth streamlining of products and lower production costs.

Productwise, New Departures assure greater accuracy and longer life . . . permit higher speeds and reduce maintenance . . . resisting *all* loads from *all* directions.

The Great Ball of New Departure symbolizes engineering excellence—and New Departure's application engineers and research facilities are always at your disposal. Keep your eye on the BALL to be sure of your BEARINGS!

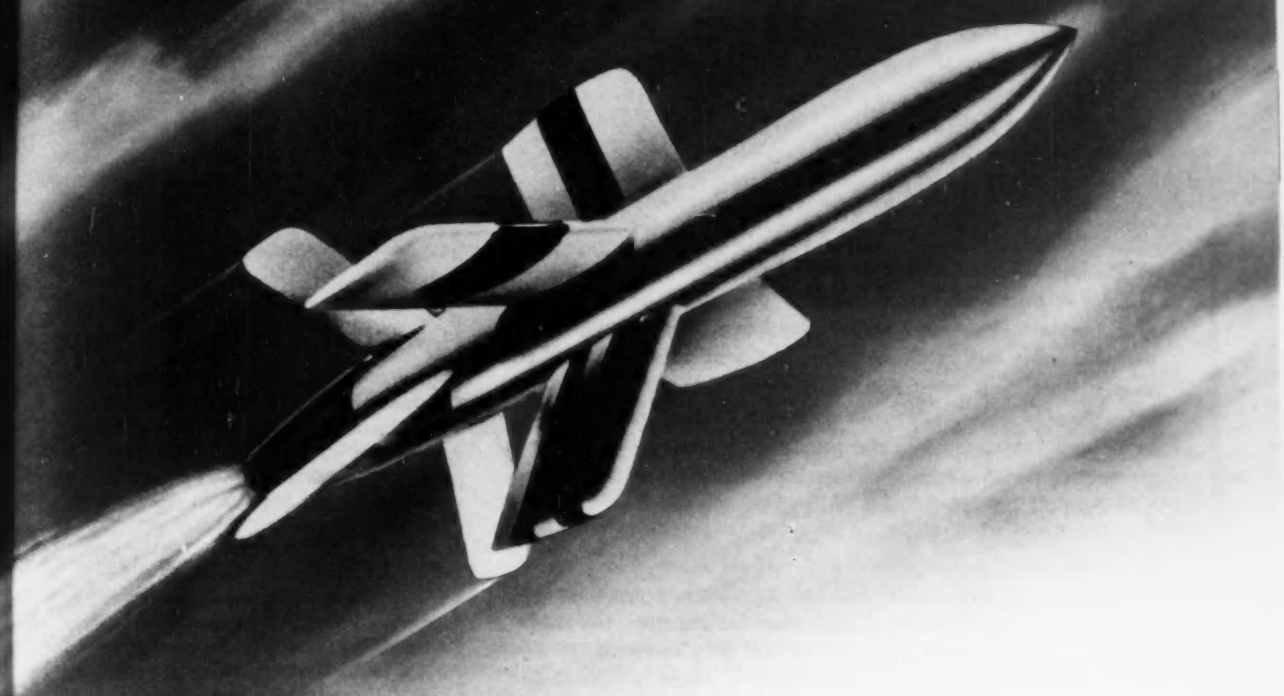
NOTHING ROLLS LIKE A BALL

NEW DEPARTURE

BALL BEARINGS

NEW DEPARTURE • DIVISION OF GENERAL MOTORS • BRISTOL, CONNECTICUT

Strain Gage Transducers FOR MEASUREMENT AND CONTROL



R. J. FYFFE and A. AROBONE • M. W. KELLOGG COMPANY

No longer is the wire-type strain gage relegated to simple measurement of stresses and strains. The great versatility of this design tool is now being realized through its use in package transducers as the heart of a bridge-type sensing element. Thus, the arduous and tricky task of mounting the delicate gage assembly is minimized and the installation simplified.

Typical of the many transducers now available are the various types of load cell, torque meter, differential pressure gage and load beam. Each is precision-built and calibrated to handle a range of variables in a growing number of fields. These include transient pressures in airplane power control systems, flow of fuel to rocket engines, torque loads on high-capacity dynamometers, and dimensions on roller bearing parts.

The first of five sections in this special report covers the two classes of gage—bonded and unbonded, types of bridge circuit, amplifying and recording equipment and the systems combining these components. The four remaining sections take up the different types of transducers designed specifically for measuring pressure, flow, weight and displacement. Case histories follow each transducer section to illustrate some of the more unusual applications for strain gage transducers.

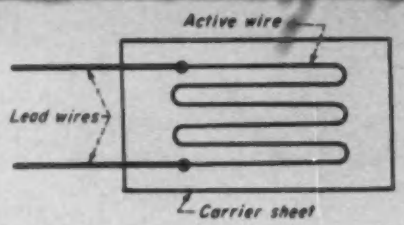


Fig. 1 – Bonded strain gage usually takes the form of a flat grid cemented to a carrier sheet.

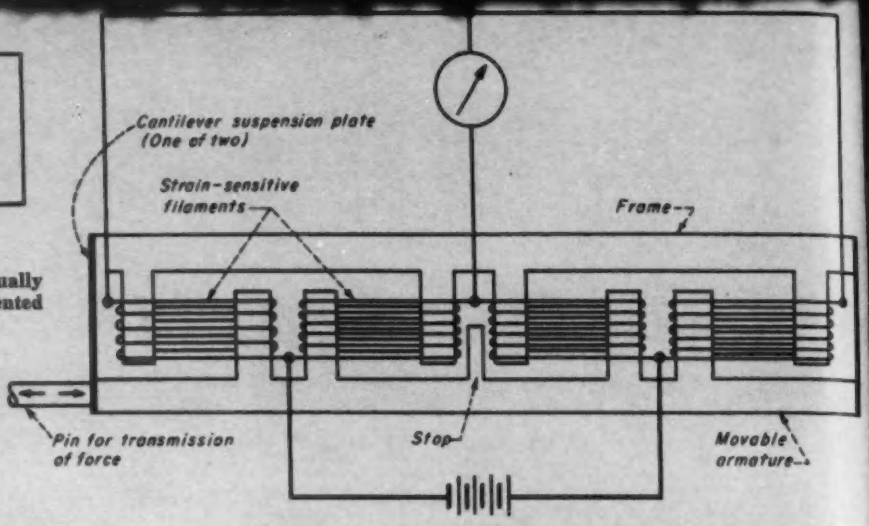


Fig. 2 – Unbonded strain gage has a stationary frame that supports a movable armature through two cantilever plates.

WIRE RESISTANCE STRAIN GAGES have been used for years to determine forces and stresses to which materials are subjected, and have proven themselves an invaluable tool in determining the properties of materials under operating conditions. Information such as strength of materials under static or dynamic loading, the resonant or natural frequency of a member, and the static and dynamic stresses to which a structure is subjected during actual operation can all be determined with these gages.

Considerable practice and experience is generally needed to obtain good performance and results from strain gages, and it is this prerequisite that has, to a large extent, limited their use in the solution of problems dealing with the measurement of pressure, flow, weight and displacement. A second limiting factor has been the lack of suitable industrial-type instruments and strain gage assemblies applicable to these problems.

During and since World War II this picture has changed rapidly, and today many measurement problems heretofore considered outside the field of strain gage measurement are being solved with this versatile instrument.

Principle of Gage Operation

THE WIRE RESISTANCE STRAIN GAGE is simple in operation and construction. When a wire is stretched elastically, its length and diameter are altered, resulting in a change of electrical resistance in the wire. It is this change in resistance that is measured and recorded. Stretching a wire 0.1 percent diminishes its diameter (with constant volume) by a factor of 0.3 in accordance with Poisson's ratio, and produces a change in the resistance of 0.17 percent.

In strain gaging, "change in resistance" is considered in terms of "change in strain" and is expressed as a ratio called *strain sensitivity* or *gage factor*. Symbolically, gage factor becomes

$$\frac{\Delta R}{R} \Big/ \frac{\Delta L}{L},$$

where ΔR represents resistance change in a total gage resistance R, divided by the corresponding change in length in a total length of conductor L. In actual practice, for reasons unknown, measured gage factors differ from the theoretical values for various types of resistance wires. Each factor is, however, the same, whether the gage is in compression or tension.

Basic Forms of Strain Gage

At present, two basic forms of wire resistance strain gages are widely used. These are the *bonded type* and the *unbonded type*. The bonded gage usually takes the form of a flat grid as shown in Fig. 1. To obtain maximum performance, the active element of resistance wire should be as near as possible to the surface of the member under study. The most effective method is, of course, to cement the wire directly to the surface of the member, but the difficulty of handling the 0.001-in. dia wire has necessitated cementing the grid to a carrier sheet that may be paper or paper impregnated with plastic. The carrier must be weak to allow the transfer of the strain to the wire via the cement. At the same time, the wire must be small so that the cement, because of the relative masses, is stronger than the wire which conforms to the contours of the cement. In this way, compressive as well as tensile strain can be transmitted.

Wire sizes of one to one and a half mils are generally used. This practice results in a convenient wire length to obtain a desired gage resistance without resulting in a grid of excessive area. The *basic standard gage* has a resistance of approximately 120 ohms, and passes about 25 mil-

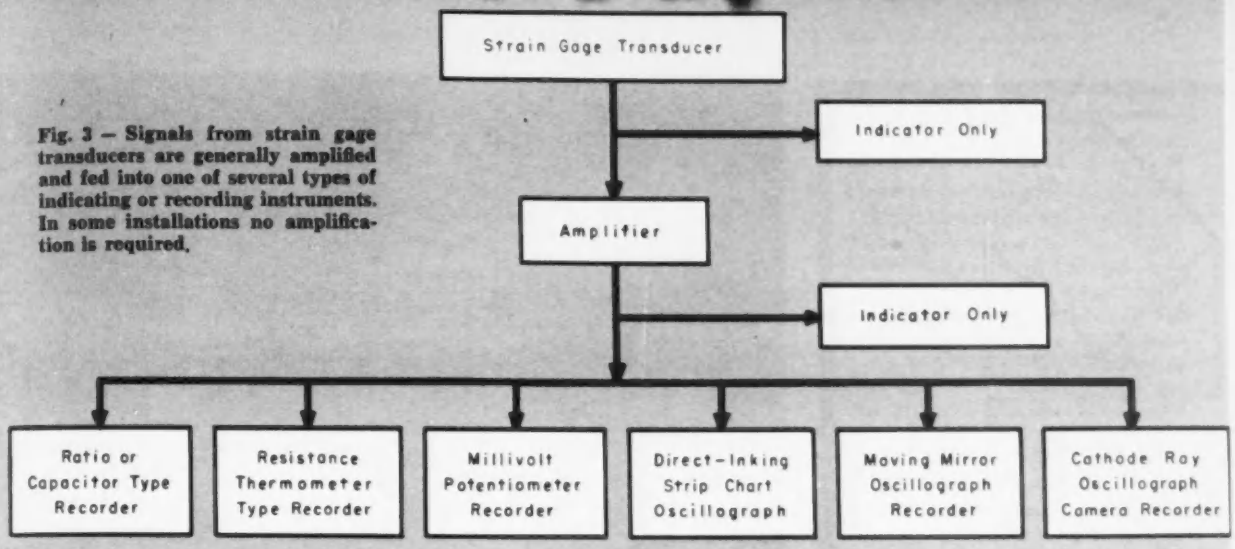


Fig. 3 – Signals from strain gage transducers are generally amplified and fed into one of several types of indicating or recording instruments. In some installations no amplification is required.

liamperes of current in a 6-v bridge circuit. The 120-ohm resistance is large compared to the nominal resistance of lead wires and is high enough not to be greatly affected by switching resistance.

Many different types of bonded gages are available with resistance values from 60 to 5,000 ohms, and effective gage lengths from $\frac{1}{16}$ to 6 in. Choice of resistance wire for these gages is based on the following factors, in the order of their importance:

(a) Maximum gage factor or sensitivity.
(b) Maximum resistance per unit length.
(c) Minimum temperature coefficient of resistance.
(d) Minimum coefficient of linear expansion.
(e) Maximum melting point.
(f) Minimum thermo-electric tendency at connections.
(g) Optimum flexibility, ease of soldering and negligible hysteresis loop in cycle of stress.

Advance, Copel or Constantan wire, all of which have a nominal composition of 45 percent Ni and 55 percent Cu, are used for both static and dynamic testing applications. Iso-elastic wire with a composition of 36 percent Ni, 8.0 percent Cr and 0.5 percent Mo is used for dynamic testing only. Gages of this wire provide about six times the voltage output of the copper-nickel gages, but have a temperature resistance coefficient varying from 25 to 50 times greater. The higher output requires less amplification for the measuring instrument, resulting in an appreciable saving of cost in instrumentation.

The cement used in bonding the gage to the strain member is extremely important to the proper operation of the gage. For permanent installation and for use in long-duration exposure up to 300 F or short-duration exposure up to 500 F, gages are phenolic-resin bonded and baked in place. Commercial bonded strain gages are manufactured under extremely close quality control and generally guaranteed to within $\pm$ one percent of the stated gage factor value. Resistance tolerance is usually $\pm$ 0.25 percent of nominal value.

It is possible to obtain factory built bonded strain gage bridge assemblies for many measurement problems. For the measurement of pressure, one manufacturer uses a pressure sensitive tube with strain gage grids bonded to the outside surface. The gas or liquid pressure being measured causes the tube to expand and stretch the gage grids, thus increasing the resistance. For the measurement of weight, the sensitive element is a rectangular steel column with gages bonded to the sides. Under load, the dimensions of the column change slightly, stretching the wire of the grids. Drawbar pull is measured in much the same way. For measurement of acceleration, gages are placed top and bottom of a weighted cantilever beam, or on an unweighted beam to measure large or small deflections or displacements. These units and various others are discussed in detail in the pages that follow.

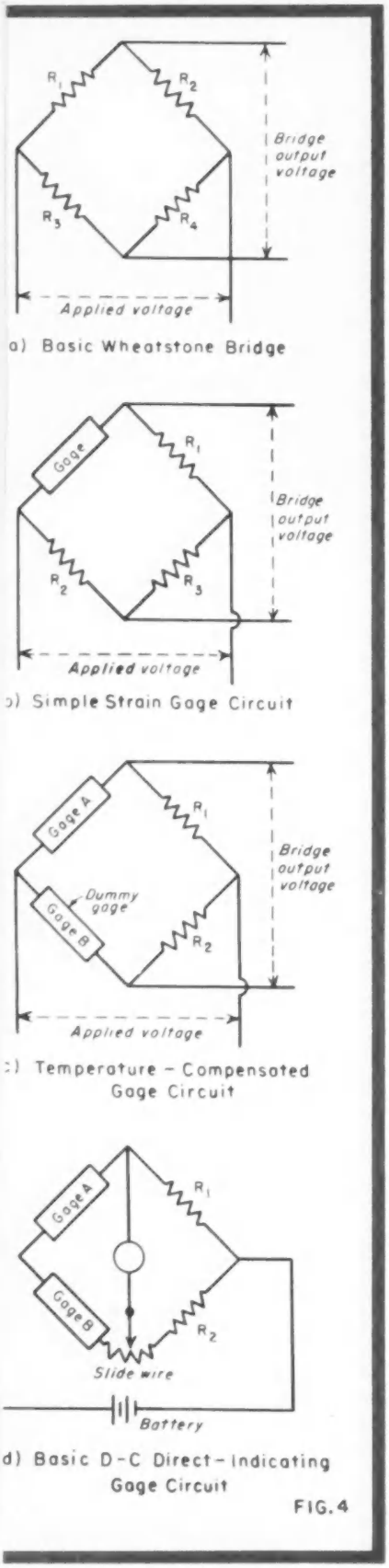
Unbonded Strain Gage

The unbonded wire strain gage, Fig. 2, consists of a stationary frame which supports a movable armature through thin cantilever plates. The strain-sensitive wire is strung under initial tension as a filament between pins located on the frame and armature. When the armature is displaced longitudinally, the filament is elongated or shortened depending on the direction of displacement, causing an increase or decrease in resistance, respectively.

Four filaments are generally used in each gage and these are connected in the form of a conventional Wheatstone bridge. As the armature is moved longitudinally by an external force, the strain increases in one pair of filaments and decreases in the other pair. An initial tension applied to the wires during assembly serves to keep them under some residual tension even when the armature is in either extreme position. Armature travel is limited by a stop which protects the wires against overload, the maximum displacement being about 0.0015 in. each side of center.

As stated, nominal bridge resistance can be from 60 to 5,000 ohms. Input voltage varies from 5 to 60 volts a-c or d-c with open circuit outputs of 6 to 175 mv full range, and closed circuit outputs of from 30 to 200 microamperes, full range. Unbonded gages have an accuracy and linearity of one percent of full scale or better and their resolution is 0.1 percent of full scale or less.

As with bonded gage assemblies, the unbonded type is available com-



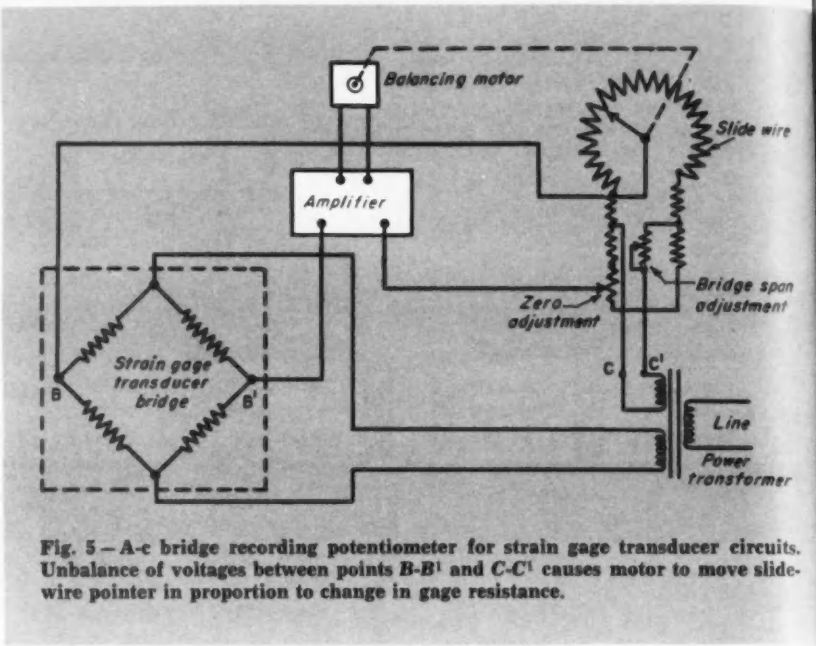


Fig. 5 – A-c bridge recording potentiometer for strain gage transducer circuits. Unbalance of voltages between points *B-B*^{1} and *C-C*^{1} causes motor to move slide-wire pointer in proportion to change in gage resistance.

pletely assembled ready for operation. For the measurement of pressure, the armature is connected by a pin to a metallic bellows or diaphragm. By applying pressure to one side of a bellows and venting the other to atmosphere, gage pressure can be read; if the bellows is evacuated, absolute pressure is measured.

Strain-Measuring Systems

As with the thermocouple in a temperature-measuring system, or an orifice in a flow-measuring system, the strain gage is of no value by itself. It is the sensitive element or transducer in a strain measuring system which must also include an indicating or recording device, and in many cases, some auxiliary equipment as well.

The remarkable progress made by manufacturers of strain gage units has been paralleled by the development of recording and indicating instruments. Many well known industrial companies supply indicators or recorders calibrated directly for use with strain gage pickups. Thus, pressures can be measured and indicated directly in terms of pounds per square inch, force or weight indicated directly in pounds, displacement directly in inches, and many other variables, all measured and translated into appropriate units. These instruments are as simple to install and operate as the potentiometer pyrometer or electrical resistance thermometer, and companies guarantee their industrial strain gage indicators and recorders to be within the same accuracy tolerance as their temperature measuring instruments.

In strain gaging, the problem of measuring and recording resolves itself down to the function of measuring or recording resistance changes as they occur in the gages. Fig. 3 shows in block-diagram form the wide range of indicating or recording instrumentation to which wire strain gages are adaptable. Table I lists the characteristics of each measuring instrument.

Wheatstone Bridge Circuits

Strain gages are usually connected so as to unbalance a four-arm Wheatstone bridge circuit, Fig. 4 (a), when its resistance is changed by stress. All of the instruments in listed Table I operate to translate this unbalance into a readable indication or record.

If a strain gage is connected as shown in Fig. 4(b), so that the only source of unbalance is the change of resistance in the gage resulting from the application of strain to the gage, the difference in potential across the output terminals becomes a measure of that strain. This potential can be measured by a sensitive voltmeter.

This simple application of the strain gage has one serious defect. The wire used in the gage is temperature sensitive in addition to being strain sensitive. The potential output is therefore the combined result of strain and temperature.

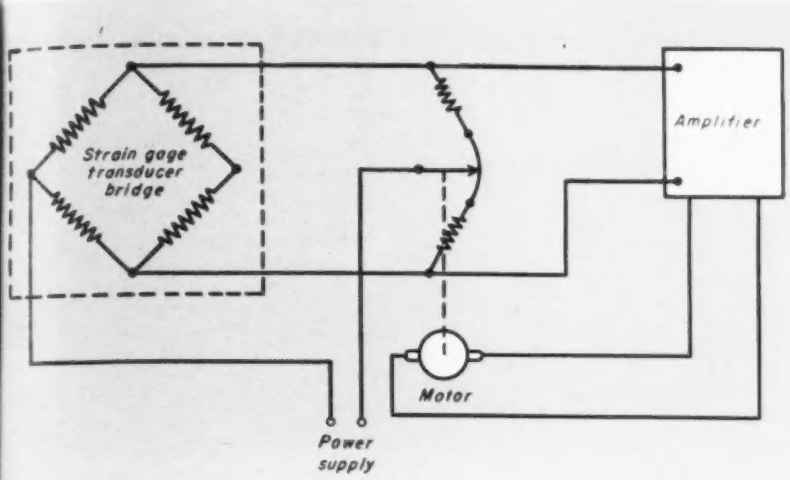


Fig. 6 – Resistance thermometer recorder has two arms of bridge within the instrument and the other two arms in the transducer.

To cancel out the effect of temperature on the gage wire, a second or dummy gage is used in the circuit as shown in Fig. 4(c). This second gage is mounted on an unstressed piece of the same material as the stressed member. To avoid differences in temperature, the two gages are located close together. Thus, resistance changes caused by temperature alone are the same for both of the bridge arms in which these gages are located, and temperature has little influence on the measurement of the stress-induced strain. The measurement does, however, include strain caused by thermally-induced stresses in the metal, but it is a true measure of stress, whether the stress results from temperature of applied force or load, or both. The function of the dummy gage is therefore to compensate for the undesired effects of temperature.

These temperature effects are due to (1) the thermal coefficient of resistance of the gage itself (as when mounted on a material of zero thermal coefficient of expansion), and (2) the thermal expansion strains in the material on which it is mounted. The two effects combine to determine the overall thermal coefficient of the gage in any given installation. The circuit shown in Fig. 4(c) is useful for measuring static strains or the static component of a varying strain, and will operate with d-c or a-c power. Using direct current, battery powered, the circuit may take the form of Fig. 4(d) with a small slide wire introduced between the fixed resistors to balance the bridge at the start of the test. A light-spot galvanometer can be used for indicating unbalance; or for direct reading, a sensitve microammeter or milli-voltmeter with proper characteristics can be used without amplifier to replace the galvanometer. These systems are limited to steady strain or strain that changes no faster than one cycle per second.

Signal Amplifiers

To obtain sufficient power to drive indicating meters, pen and ink recording mechanisms, the motors of self-balancing bridges, oscillograph galvanometers, or cathode ray oscil-

Table I–Characteristics of Recording Instrumentation

TYPE OF INSTRUMENT	TYPE OF RECORD	RECORDING MEANS	CHART WIDTH, IN.	CHART SPEED	NUMBER OF POINTS PER INSTRUMENT	CALIBRATION	FREQUENCY RESPONSE, CPS	NOMINAL ACCURACY % OF RANGE	MOUNTING
Light-spot galvanometer	Indicates only	Manual recording	–	–	Multiple with switching	Required	1.0	¼ of 1%	Panel or table
Microammeter	Indicates only	Manual recording	–	–	Multiple with switching	Required	1.0	2%	Panel or table
Potentiometer	Single point, curve line, multiple point or curve print	Pen and ink or print	11	¾"/hr to 1"/sec	1, 2, 3, 4, 5, 6 or 8	Direct	0.5	¼ of 1%	Panel
Resistance thermometer	Single point, curve line, multiple point, or curve print	Pen and ink or print	11	¾"/hr to 1"/sec	1, 2, 3, 4, 5, 6 or 8	Direct	0.5	¼ of 1%	Panel
Ratio or capacitor	Single point, curve line, multiple point or curve print	Pen and ink or print	4½	¾"/hr to 3"/sec	1, 2, 3 or 4	Direct	0.5	¼ of 1%	Panel
Direct writing oscillograph	Single or multiple point, curve line	Pen and ink or heat-sensitive paper	2½ to 12	0.1 to 5" per sec	1, 2, 4 or 6	Required	100	1%	Table
Moving Mirror oscillograph	Single or multiple point; curve line	Film or light sensitive paper	6 to 10	1 to 120" per sec	6, 9, 12, 18, 24 or 36	Required	0-2,000	2%	Table
Cathode ray oscilloscope and camera	Single or multiple point; curve line	Film	1 to 6	1.6 to 200 per sec	1, 2, or 6	Required	0-50,000	2%	Table

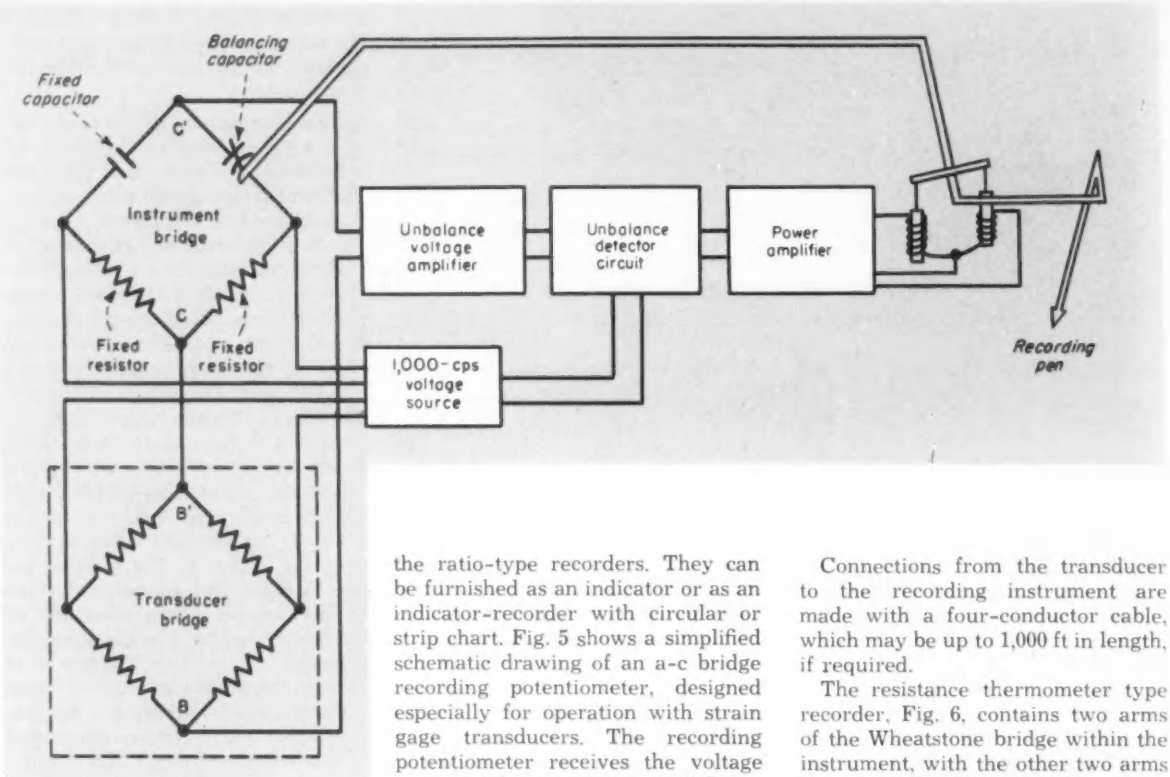


Fig. 7 – Ratio type recorder consists of transducer and instrument bridges excited by 1,000 cps oscillator. Balancing unit moves rotor of balancing capacitor to equalize voltages between points *B-B*^{1} and *C-C*^{1}.

loscope light spots, it is necessary to amplify the weak but accurate signal produced by the unbalance of the strain gage bridge. Amplified bridge unbalance will operate servomechanisms, run motors, turn valves, trigger safety power cut-off, or can be built into machinery as permanent installations for load measurements, regulation or control means. Bridge unbalance signals can be telemetered by radio or commutated electronically so as to read a large number of parallel bridges at ultra-high speeds.

Alternating current amplifiers are preferable to direct current means because a-c amplification is relatively simple as compared to d-c amplification. Alternating current circuits have the added advantage of automatically eliminating the contact potentials or thermal emf's in the gage resulting from changes in polarity.

Self-balancing bridge instruments with reversing-motor drive are of most general interest. This group of instruments includes the potentiometer, the resistance thermometer, and the ratio-type recorders. They can be furnished as an indicator or as an indicator-recorder with circular or strip chart. Fig. 5 shows a simplified schematic drawing of an a-c bridge recording potentiometer, designed especially for operation with strain gage transducers. The recording potentiometer receives the voltage output of the transducer, amplifies it, and feeds the amplified output to a motor which moves the potentiometer slide wire to the point at which a known portion of the voltage between points C and C^1 is precisely equal to the transducer output voltage between the bridge points B and B^1. When this balanced condition is achieved, the voltage appearing at the amplifier input is zero and there is, consequently, no output to the motor. When a change in the variable occurs, the balance is disturbed and the difference appears across the amplifier. The amplified output is of the proper phase to turn the motor in the direction that will move the slide wire contact to restore the balance. The slide-wire contact is also linked to a pointer and pen that makes a trace on the chart corresponding to the transducer output. Since the transducer output changes in proportion with the force acting on the strain gages, the potentiometer can be calibrated directly in terms of this force. Power for the a-c bridge is furnished from the transformer incorporated in the potentiometer.

The effects of ambient temperature around the transducer are nullified by using active gages in all four arms of the Wheatstone bridge circuit. Since all four gages are affected equally, the ambient temperature effect is reduced to a negligible factor.

Connections from the transducer to the recording instrument are made with a four-conductor cable, which may be up to 1,000 ft in length, if required.

The resistance thermometer type recorder, Fig. 6, contains two arms of the Wheatstone bridge within the instrument, with the other two arms located within the transducer. The two arms in the recorder are composed of a slide wire with a motor-driven contact. An unbalance of the bridge, resulting from the change of resistance of the transducer element, produces an output which is amplified and fed to the rebalancing motor. The amplifier contains phase sensitive circuits that drive the motor in the proper direction and a recording pen is connected to the contact, permitting a continuous recording of the variable.

A four-arm transducer bridge can be used with this type instrument by utilizing only two arms of the transducer to complete the bridge. The remaining two arms are inactive and appear as a fixed resistance across the amplifier terminals. These two arms are in series and, as the measured variable changes, they undergo resistance changes that are equal and opposite, so that their total resistance is constant.

The ratio type recorder is shown in Fig. 7. The transducer consists of four strain gages wired in the form of the Wheatstone bridge and excited from a low-voltage 1,000 cps oscillator in the instrument. The instrument measuring circuit or internal bridge consists of two fixed resistance arms and two capacity arms. One of the capacity arms is a fixed capacitor and the other is a variable or balancing capacitor. The internal

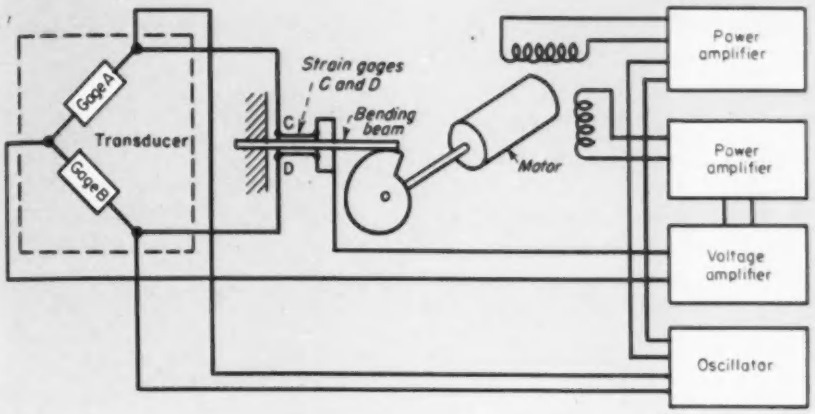


Fig. 8 — Self-balancing bridge recorder has bending (cantilever) beam that carries two strain gages mounted back-to-back.

bridge is excited from another secondary winding of the 1,000 cps oscillator which excites the transducer.

The transducer bridge and instrument bridge are connected as shown to an electronic balancing unit which automatically moves the rotor of the balancing capacitor to a position at which the voltage between points B and B' is equal in value to and opposite in phase to the voltage between points C and C'. A null balance condition then exists.

While the output voltage of the transducer bridge changes as a function of change in variable, the instrument bridge continuously operates to maintain the null balance. The position of the balancing capacitor rotor, which is connected mechanically to a recording pen or indicating pointer, determines the amount of unbalance of the transducer bridge. Since this unbalance is proportional to the force acting on the transducer, the instrument can be made to read the variable directly.

Self-balancing bridge instruments can be obtained with either a circular or strip chart type of recording. When a record of measurement throughout relatively long periods is the primary requirement, the strip chart recorder is usually preferable. With this recorder, a record of measurements from one or multiple transducers can be obtained. Chart speeds are available from a nominal of ¾ in. per hour to one in. per sec. Instruments are available with a pen speed across an 11-in. chart of as little as one second.

In Fig. 8 is shown a block diagram of a self-balancing bridge instrument designed especially for strain gage use. Unbalance of the Wheatstone bridge drives a small two-phase motor to automatically restore balance by physically bending a cantilever beam on which two strain gages are mounted back to back. These constitute two arms of the bridge, the other two being located externally in the transducer element. The mechanical action that restores balance is also used to move the recording pen.

Directional control is obtained very simply. The two-phase driving motor is a phase discriminator in itself. One of the two phases is connected to the oscillator, the other to the gage circuit, opposing each other. When the beam is bent in one direction, one phase in the motor leads the other; when the beam is bent in the opposite direction, one motor phase lags the other. In operation, the motor maintains automatic bridge balance and phase discrimination and records at the same time.

Control can be obtained in the form of electric on-off, high-low, or proportioning action. For applications where pneumatic control is desirable, all the usual forms are available.

For the field of dynamic measurement with strain gage units, all frequencies from extremely low to impact transients can be recorded on commercial instruments, whether these be rapidly varying loads, forces, displacements, accelerations, resonance studies, measurements of peak fluid or gas pressures, water hammer, explosions such as gun firing, or dynamic torsional modes. Measurement of a lagless response has been made up to 50,000 cps and it is an accepted fact that such response characteristics go on up to much higher values.

Instrumentation for this field falls within three general classifications, with frequency response as the limitation for each class. Zero to approximately 120 cps is obtainable with the first class, zero to 2,000 cps from the second class and zero to 50,000 or higher from the third class.

Direct Writing Oscillograph

The first group includes the direct-writing type of oscillograph. These are self-contained units and can provide 1, 2, 4 or 6 records. They can draw an instantaneous graph of any electrical signal within their frequency range and display the wave shape, amplitude and frequency for immediate analysis and comparison. Variable chart speeds are provided and, depending on the manufacturer, the actual recording is obtained by either pen and ink or plastic coated heat sensitive paper marked by a heated stylus.

Amplifiers designed especially for strain gage bridge operation are available for these recorders. One manufacturer uses a conventional modulated carrier type in which the bridge is excited at 2,500 cycles by a built-in oscillator. The bridge output, which is proportional to the degree of unbalance, is amplified at 2,500 cycles, rectified by a phase sensitive detector circuit, and the resulting d-c is applied to a driver amplifier whose output is sufficient to operate the recorder. The circuits between the oscillator and the bridge proper include controls for initially adjusting both the resistive and capacitive balance of the bridge. The carrier amplifier, which follows the bridge, includes both a stepped attenuator and a smooth gain control for setting the overall sensitivity. This sensitivity in turn can be checked at any time by depressing a push button that introduces a fixed unbalance in

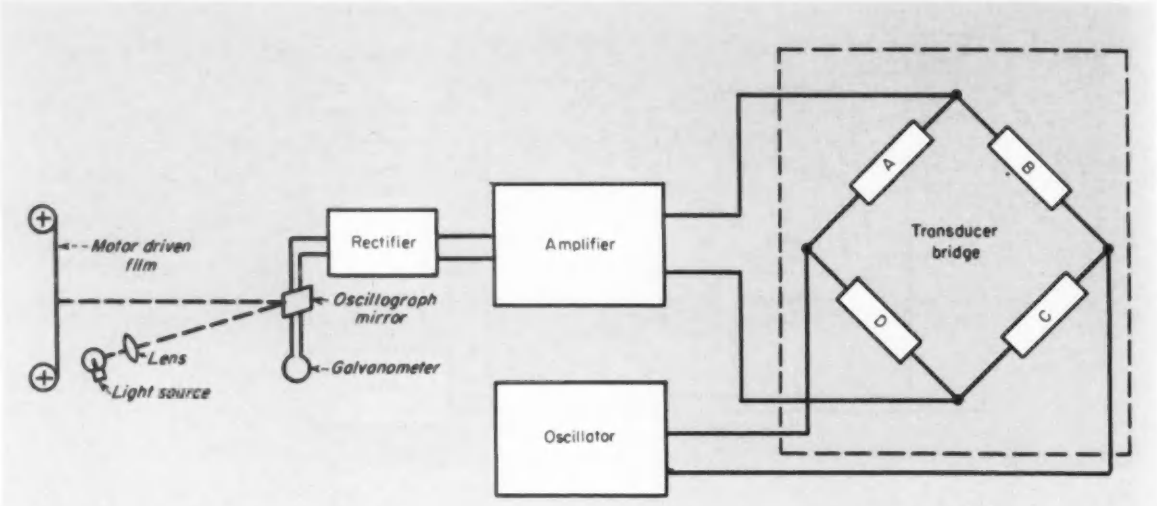


Fig. 9 – Moving mirror oscillograph contains one or more galvanometers with mirrors that direct a light beam onto moving chart (film). A viewing screen, as well as timing and numbering devices are also provided.

the bridge network. The initial position of the recording stylus on the chart is set by a "zero" control incorporated in the phase-sensitive detector system. This position is independent of the setting of the gain controls when the bridge is balanced.

To obtain quantitative data from oscillographic records, it is necessary to calibrate the transducer and recorder system. The most direct method is to apply a known increment of the force to be measured and observe the corresponding deflection of the pen. Other known forces will then cause proportional deflections. The system may also be calibrated indirectly by using the gage factor supplied by the transducer and inserting a known calibrating resistance.

Moving Mirror Oscillograph

The second class of recording systems includes the moving mirror type of oscillograph. This is the most common type of dynamic recorder covering the range from steady strains up to vibratory strains of 2,000 cps or more. The recording element is a galvanometer with a small mirror that rotates through an angle proportional to the galvanometer current, and a beam of light reflected from this mirror moves across a moving chart of sensitized paper or film. Fig. 9 shows a schematic diagram of this instrument.

Because no pen arm is required, it is possible to make oscillograph galvanometers respond accurately to frequencies as high as 5,000 cps. As many as thirty galvanometers can be mounted in a single oscillograph so that a large number of strains can be recorded simultaneously from a single chart.

Galvanometers for this type oscillograph are rated in terms of natural frequency and sensitivity. The galvanometer should be used considerably below its natural frequency, in order to obtain uniform response for all frequencies within the measurement range. In general, such a meter provides uniform response from zero frequency to a frequency between a half and three quarters of its undamped natural frequency. Thus if it is desired to record strain over the range of say, zero to 1,500 cps, the natural frequency of the galvanometer should be between 2,000 and 3,000 cycles per second.

For low frequencies, electro-magnetic damping is adequate, but at

Table II–Indicator and Recorder Manufacturers

LIGHT SPOT GALVANOMETERS	MICROAMETERS	POTENTIOMETERS	RESISTANCE THERMOMETERS
General Electric Co. Leeds & Northrup Co. Rubicon Co.	Cole Instrument Co. General Electric Co. Westinghouse Electric Co. Weston Electric Inst. Co. Wheelco Instrument Co.	Leeds & Northrup Co. Brown Instrument Co. Weston Electric Inst. Co. Tagliabue Division Rubicon Co. Bailey Meter Co. General Electric Co. Thwing Albert Co. Wheelco Instrument Co. Bristol Co.	Leeds & Northrup Co. Brown Instrument Co. Bailey Meter Co. Wheelco Instrument Co. Foxboro Instrument Co. Bristol Co. General Electric Co. Weston Electric Inst. Co., Tagliabue Division
RATIO OR CAPACITOR	**DIRECT WRITING OSCILLOGRAPH**	**MOVING MIRROR OSCILLOGRAPH**	**CATHODE RAY OSCILLOSCOPE RECORDER**
Foxboro Instrument Co.	Brush Development Co. Rahm Instrument Co. Sanborn Co. Photron Instrument Co. Edin Co.	Century Geophysical Corp. Consolidated Eng. Co. Hathaway Instrument Co. Heiland Research Corp. William Miller Co. General Electric Co. Westinghouse Electric Co.	Browning Laboratories Du-Mont Laboratories Hickok Electric Instr. Co. Radio Corp. of America Waterman Products Co. Brush Development Co. Electronic Tube Corp.

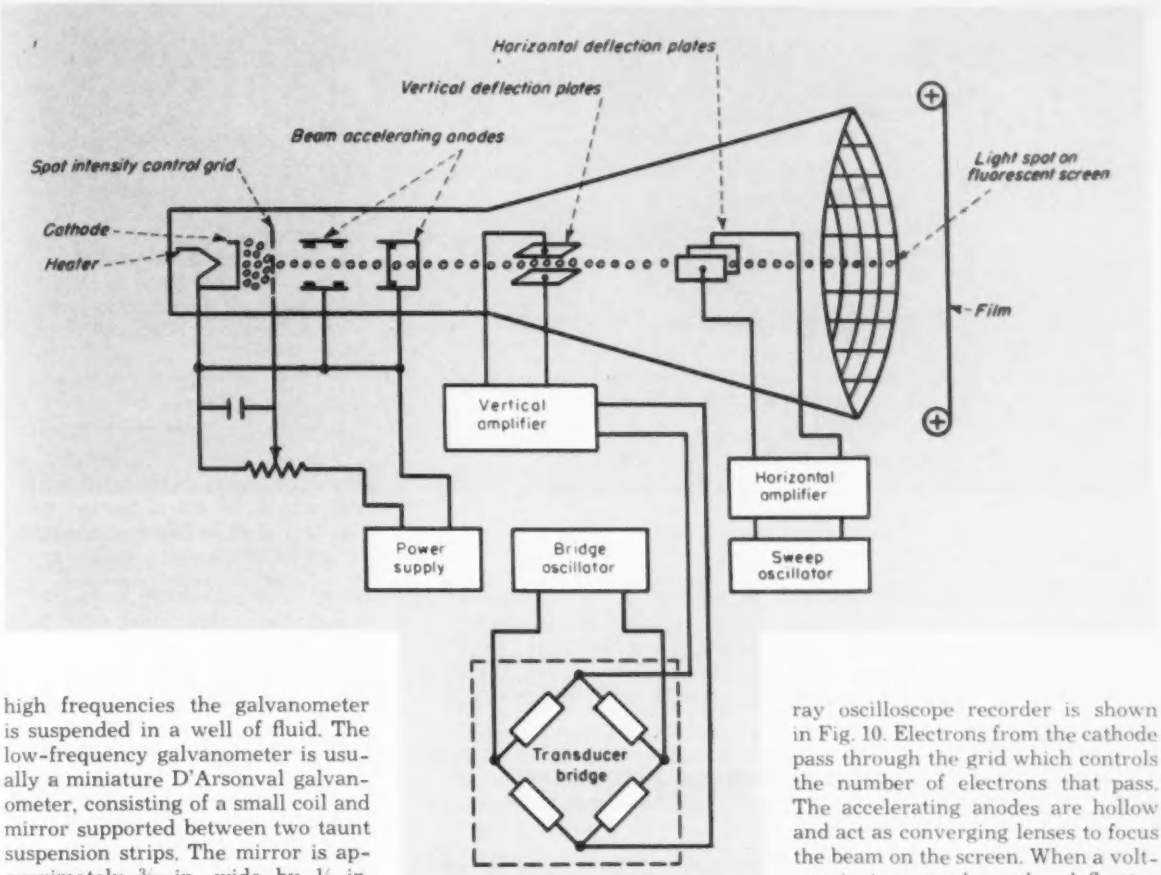


Fig. 10 — Cathode ray oscilloscope recorder is useful for dynamic operations because light spot that indicates bridge unbalance is inertialess.

high frequencies the galvanometer is suspended in a well of fluid. The low-frequency galvanometer is usually a miniature D'Arsonval galvanometer, consisting of a small coil and mirror supported between two taunt suspension strips. The mirror is approximately $^{3}/_{32}$-in. wide by $^{1}/_{8}$-in. long with a coil about $^{3}/_{8}$-in. long. This type galvanometer can be obtained with natural frequencies from 25 to 1,000 cps. It is generally used for frequencies below 300 cps. The magnetic field for multiple elements of this type is provided by a single Alnico magnet. Each element is individually adjustable to provide for location of the reflected light beam.

For high-frequency measurement, galvanometers of the Duddell or bifilar type are commonly used. These consist of a long loop of round wire or flat ribbon stretched between a pair of pole pieces, and a small mirror cemented to the loop. It can be considered as a one-turn D'Arsonval galvanometer with a large restoring force due to the double ribbon suspension at both ends.

The optical system for these instruments usually consists of an incandescent lamp and a system of lenses and mirrors that directs a beam of light onto each galvanometer mirror, from which it is reflected across the moving film. The amplified bridge unbalance flowing through the galvanometer coil swings the reflection of the spot of light in direct proportion to the transducer unbalance.

Companies manufacturing moving-mirror type oscillographs usually have available auxiliary equipment to complement their recorders for use with strain gage transducers. For low frequencies where the sensitivity and frequency response available in amplifying systems are not required and signal output is sufficient, multiple-channel bridge-balancing units are available. For the higher frequencies, amplifiers and carrier systems are available to record in the range of 5 to 2,000 cycles per second.

Cathode Ray Oscilloscope

The third class of high frequency measurement instrumentation is the cathode ray oscilloscope. This unit is extremely useful for dynamic operations as the light spot used to indicate bridge unbalance is truly inertialess, operating simply by deflection of a cathode ray, which is without weight or substance.

A schematic diagram of the cathode ray oscilloscope recorder is shown in Fig. 10. Electrons from the cathode pass through the grid which controls the number of electrons that pass. The accelerating anodes are hollow and act as converging lenses to focus the beam on the screen. When a voltage is impressed on the deflection plates, the negative electron beam moves one way or the other, the amount of deflection being proportional to the voltage.

When the strain gage transducer, powered by its own oscillator, is connected into the vertical amplifier, its unbalance affects the vertical deflection plates so as to displace the beam in proportion to bridge unbalance.

The horizontal plates are acted upon by a special sawtooth oscillator that traces the bridge unbalance wave form as a function of time by causing the spot to sweep horizontally across the screen at a uniform rate and then to return extremely rapidly to its initial position for a second sweep. The unit can be used directly as an indicator, or where recording is required, high speed moving picture cameras are available, which fit over the screen of the scope and photograph the movement of the cathode ray. With suitable calibration of the spot deflection versus the force being measured, records of high frequency phenomena can be analyzed.

The descriptions above do not, of course, cover the field of available equipment completely, but do indicate the variety available. Table II

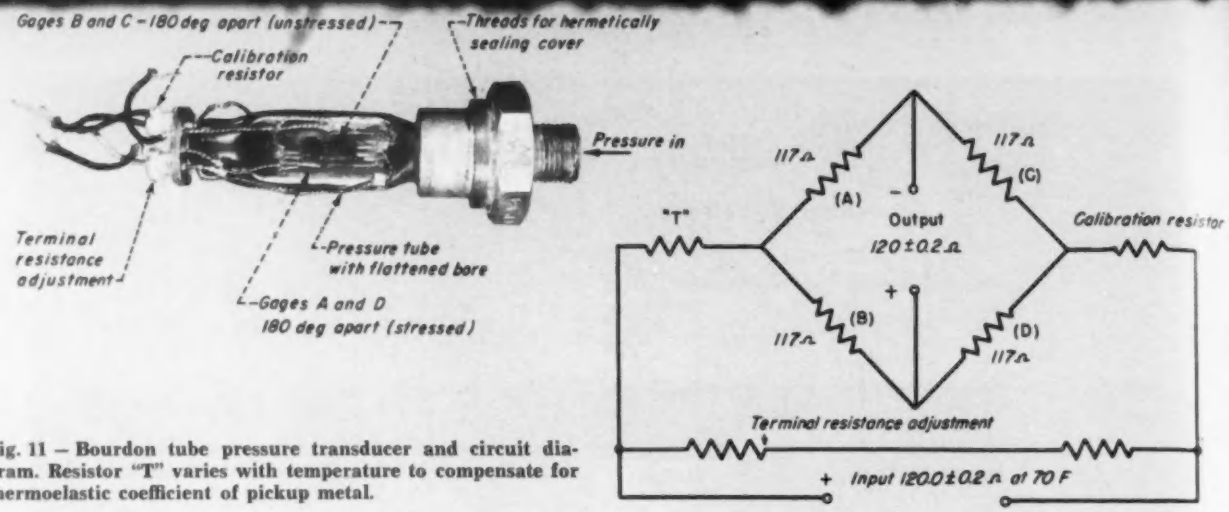


Fig. 11 – Bourdon tube pressure transducer and circuit diagram. Resistor "T" varies with temperature to compensate for thermoelastic coefficient of pickup metal.

lists companies known to have equipment suitable for use with strain gage transducers. It is strongly suggested that specific problems concerning recording instrumentation be referred to these companies and the transducer manufacturers. Descriptive and technical literature is available which covers specific requirements in much greater detail.

Pressure Transducers

Pressure is the most commonly measured variable in the field of instrumentation. Because the strain gage pressure transducer operates entirely without moving parts, and can follow high or low frequency pressure oscillations, it has assumed a position of major importance in this field.

A strain gage pressure transducer consists of an elastic element that converts pressure into displacement, and wire resistance strain gages for measuring this displacement. These assemblies are manufactured in many different forms, but only those most generally available as completely packaged units are discussed, and listed in Table III.

Pressure transducers can be classified according to the type of elastic element used. In Class I, the Bourdon tube type, the heart of the cell is a pressure sensitive tube to which are bonded four resistance gages wired in the form of a Wheatstone bridge. When all four arms of the bridge are active, as is usually the case, it is not necessary to make specific provisions for mounting inactive gages. Temperature compensation is extremely important however, since even small temperature changes produce spurious readings unless all four bridge arms are affected alike. Increased bridge output, as well as a high sensitivity and reading accuracy, are added advantages derived from using four active bridge arms.

Service conditions, whether corrosive or not, and application requirements govern Bourdon tube material selection. The characteristics of the material to which transducers are bonded determines the sensitivity of strain-sensitive elements. For standard operating conditions, Type 410 stainless steel, which has a very high elastic limit, has proven satisfactory because it furnishes over-range protection to approximately 120 percent of the rated operating pressure. For applications in which highly corrosive gases or liquids are encountered, Bourdon tubes can be fabricated from materials other than 410 stainless steel. These include phosphor bronze, Type 316 or 347 stainless steel, KR Monel, and Haynes Stellite alloy 605. For gases and non-corrosive atmospheres and liquids, ordinary high-tensile strength carbon steel is permissible.

The pressure sensing element is hermetically sealed and operates without moving parts, so that under normal operating conditions, an extended life can be expected of these commercial units. Since signal transmission is obtained electrically, indicators or recorders can be located at any desired point, either near to or remote from the sensing element. A Baldwin fluid pressure cell with the hermetically-sealed cover removed is shown in Fig. 11, along with the circuit diagram for this type transducer.

The Bourdon tube sensing element is available for pressure ranges from zero to 100 psi to approximately zero to 50,000 psi. Their calibration is usually accurate to within ± ¼ percent of full range at 70 F for any point from zero to 100 percent of capacity.

The natural frequency response of this pressure element is approximately 700 to 1,000 cycles per sec, depending upon pressure range and material of the Bourdon tube. To measure higher frequencies, a straight-bore tube is available. In such a unit, the tube is not flattened and the resistance gages are actually wrapped around the tube. This device is said to give frequency responses of approximately 2,000 cycles per second, again depending on range and material of the tube.

Cantilever Sensing Element

For more efficient measurement in the lower pressure ranges, the Class II or cantilever type system actuated by a pressure sensitive element is utilized. For pressures above atmospheric, a single bellows is used; for differential pressures, an additional bellows is inserted as indicated in Fig. 12. When measuring absolute pressure, the additional bellows is evacuated.

The electrical circuits in the cantilever sensing element are similar to that of the Bourdon-tube type. The bellows must be dimensionally stable,

corrosion resistant and flexible, and the reference spring or cantilever beam designed to require minimum energy from the bellows. It is important to have a low-energy beam so that the bellows displacement for any given diameter bellows and pressure range can be minimized.

To maintain sensitivity essentially constant with respect to temperature, the dimensions of the cantilever beam are chosen so as to compensate for the temperature coefficient of Young's modulus. Another method of doing this is to install a resistor or resistors, which vary with temperature to compensate for the thermoelastic coefficient of the bellows material.

An advantage of the cantilever reference spring is the extremely low hysteresis and after-effect that can be maintained. Hysteresis effects in this type transducer are usually in the range from 1/6 to ⅛ percent of full scale. After-effect is the difference of zero reading before and after a pressure has been applied, and is usually in the neighborhood of 0.1 percent.

In addition to the bellows-actuated cantilever beam, there are also variations. A diaphragm, piston or other pressure sensing element can be used to move the beam. In a succeeding section of this article regarding flow meters, the diaphragm method is discussed in detail.

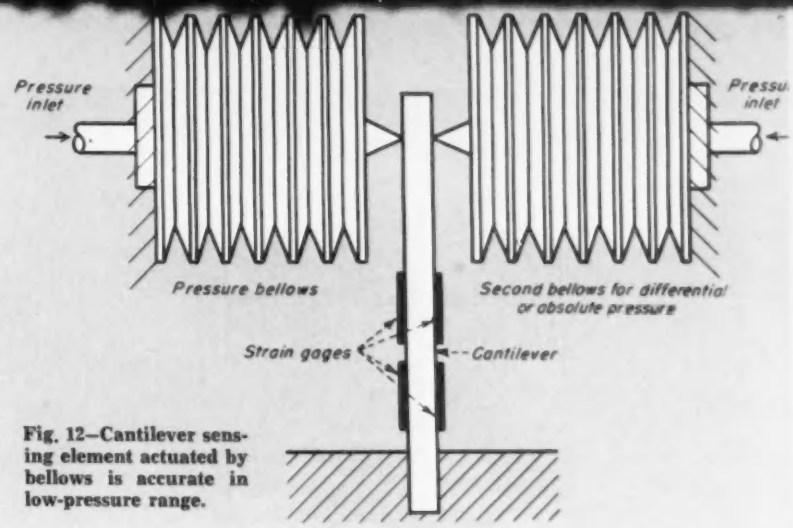


Fig. 12—Cantilever sensing element actuated by bellows is accurate in low-pressure range.

Ring Pressure Sensing Element

Another in the family of strain gage pressure transducer elements is the Class III or Flader sensing ring. In this adaptation of the strain gage principle, four active gages are bonded to a small cylindrical sensing ring as shown in Fig. 13. The gages are connected as a Wheatstone bridge and small spools of compensating wire are placed in the circuit to balance the bridge and provide correction for zero shift and temperature sensitivity. The sensing ring is deflected to a maximum of approximately 0.001 in. by the action of a piston. A thin diaphragm separates the piston from the pressure inlet containing the activating fluid or gas. The top portion of the instrument, which forms the cover for the pressure cell, can be either aluminum, if the instrument is used for measuring pressures in air and other non-corrosive fluids; or stainless when used with corrosive fluids.

Ring type elements can be constructed in ranges from zero to 25 lb or from zero to 10,000 lb. They will operate in any position and have a natural frequency in excess of 1,500 cps. These elements are bonded firmly in place and are not subject to spurious signals when subjected to shock or vibration. Difference of range is obtained merely by changing the area of the piston. The output voltage versus applied pressure characteristic of this gage is linear.

Catenary Diaphragm Sensing Element

This Class IV transducer is particularly suited for pressure measurements in all types of internal combustion engines. Accuracy at both

Table III—Characteristics of Pressure Transducers

Class of Sensing Element	Type Strain Gage	Available ranges, psi	Accuracy, % full range	Input Current	Temperature Limit, F	Natural Frequency, cps	Manufacturer
I—Bourdon tube and bellows	Bonded	0-10 to 0-50,000	±¼	A-C or D-C	250	300 to 1,000	Baldwin-Lima-Hamilton Corp.
I—Bellows and diaphragm	Unbonded	0-0.05 to 0-10,000	±½	A-C or D-C	−65 to +250	270 to 10,000	Statham Laboratories Inc.
II—Bellows and cantilever beam	Bonded	0-10 to 0-2,500	±½	A-C or D-C	—	—	Trans-Sonics Inc.
III—Ring type	Bonded	0-25 to 0-10,000	±1	A-C or D-C	−50 to +170	Above 1,500	Fredric Flader Inc.
IV—Catenary Diaphragm	Bonded	−15-100 to −15-10,000	±1	A-C or D-C	High—air cooling supplied	45,000	Control Engineering Corp.

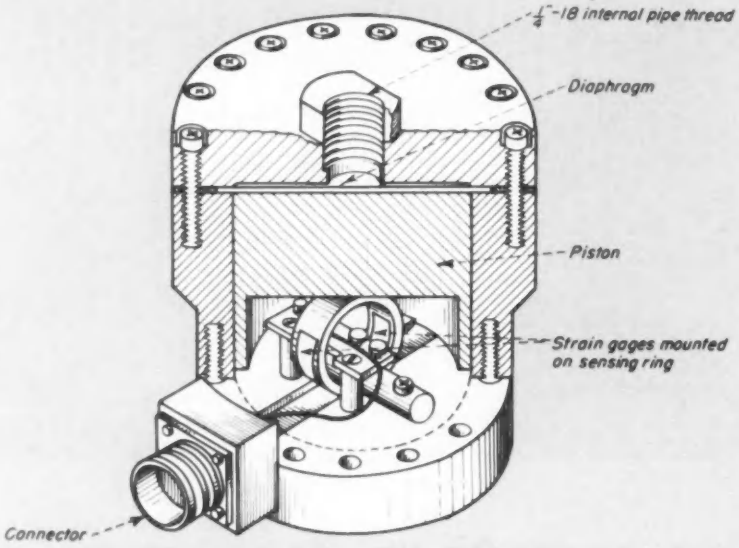


Fig. 13 – Flader sensing ring carrying four active strain gages is deflected by pressure exerted through diaphragm and piston.

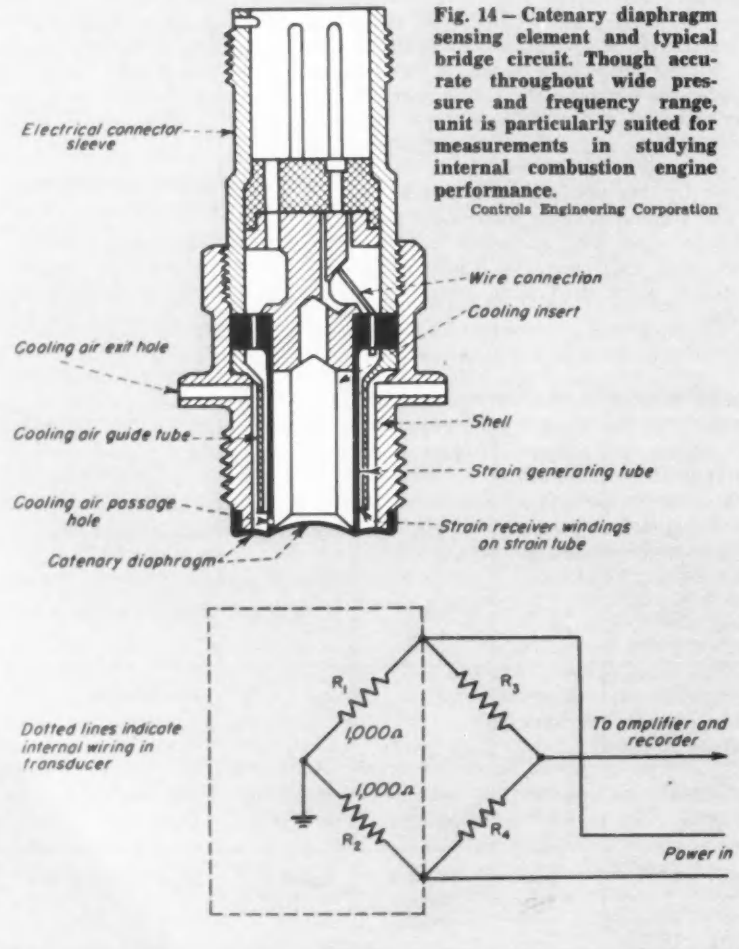


Fig. 14 – Catenary diaphragm sensing element and typical bridge circuit. Though accurate throughout wide pressure and frequency range, unit is particularly suited for measurements in studying internal combustion engine performance.
Controls Engineering Corporation

high detonation frequencies and lower power stroke frequencies is greater than heretofore obtainable. Static or low-frequency pressures as in hydraulic and pneumatic systems or in steam engines can be measured equally as well. These elements can also be used in the fields of high pressure chemical reactions at elevated temperatures, detonation pressures in explosive charges, rocket pressures, and many other fields of pressure measurement where very high frequencies are encountered.

This catenary sensing element is based on the work of Dr. C. Stark Draper and Dr. Y. T. Li of the Massachusetts Institute of Technology. Because of its unique construction, the pickup minimizes the effects of temperature gradients, vibrations, mounting stress and calibration drifts.

At the bottom of the view in Fig. 14, is a thin diaphragm with two catenary-shaped depressions. Resting in the circular groove formed by the intersection of the two catenaries is one end of a thin-walled tube, the upper end of which is developed into a heavy flange clamped securely to the main body. This is the strain generating tube on which are two 1,000-ohm, single-layer strain gage windings. One winding is applied longitudinally and the other circumferentially. The strain gages are noninductively wound and electrostatically shielded.

Operation of the pickup is such that when pressure is applied to the outside of the diaphragm, the strain tube is compressed along its axis and expanded around its circumference. This increases the diameter and decreases the length of the longitudinal winding, and decreases the diameter and increases the length of the circumferential winding, thereby decreasing and increasing their resistances, respectively. The windings form two arms of a Wheatstone bridge circuit, thus any resistance change due to temperature cancels out. Fig. 14 also shows the circuit used with these catenary transducers.

Cooling air can be supplied to the pickup when it is mounted in a heat-generating device. Referring to Fig. 14, air is introduced through the electrical connector and divided into two paths. Some air goes down the center of the "cooling insert" and cools the center of the diaphragm, then passes radially through small holes drilled in the end of the strain tube. The air guide tube conducts the second path of air over the surface of the gage windings. It then rejoins the other air stream and is

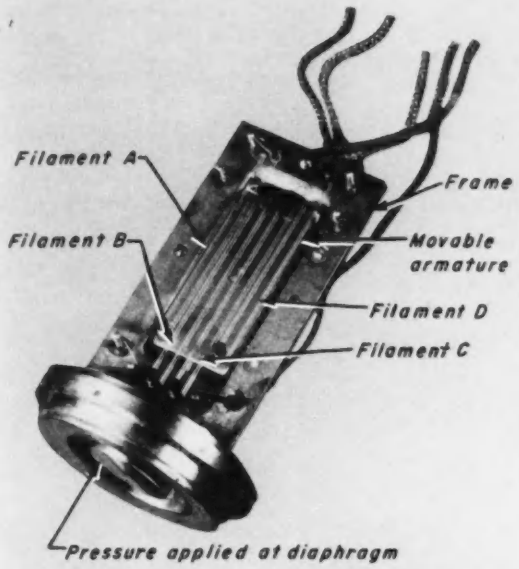


Fig. 15 – Statham pressure transducer has frame with armature that moves relative to it. Being sealed within the case, the four gage filaments are well protected.

TYPICAL SPECIFICATIONS FOR PRESSURE TRANSDUCERS

Accuracy and linearity: 1% of full scale or better

Resolution: 0.1% or better

Temperature limits: —65 to 250 F

Input current: Alternating or direct

Breakdown voltage to ground: 200 volts rms

Resistance: 60 to 3,000 ohms

Input voltage: 6 to 30 volts

Open circuit outputs: 18 to 80 mv, full range

Closed circuit outputs: 100 to 200 microamperes, full range

Ranges available: From 0-0.05 psi to 0-10,000 psi

Natural frequency: 270 to 10,000 cps depending on range

Materials of construction: Optional, depending on requirements

vented to the atmosphere through the "air exit holes." Air cooling will keep the internal parts of the transducer at temperatures below 200 F for ordinary combustion engine operating conditions.

By using a catenary-shaped diaphragm, thinner materials can be used than for a flat type at the same pressure. This design has three advantages: (1) a thin diaphragm has a very low spring rate, and therefore the force exerted by the diaphragm on strain tube as a result of temperature gradients or fluctuations in the diaphragm can be kept to a minimum; (2) the diaphragm mass is low, thus keeping natural frequency high; (3) since the strain tube is secured to the main body at one end only, with the thin diaphragm exerting negligible force on the free end due to its low spring rate, thermal expansion and mounting stress forces of the main body do not cause appreciable deformation of the strain tube.

The low mass of the diaphragm, coupled with the high natural frequency of the strain tube (about 45,000 cps) results in a unit that is insensitive to vibrations up to about 20,000 cps, which is well above the range encountered in most work.

Combinations of these various characteristics result in a transducer for which the relationship between pressure input to output voltage change does not deviate from linearity by more than one percent of full scale.

Pressure ranges that are currently available in this type pressure pickup, range from 100 to 10,000 psi. For corrosive atmospheres, 18-8 stainless steel parts are used.

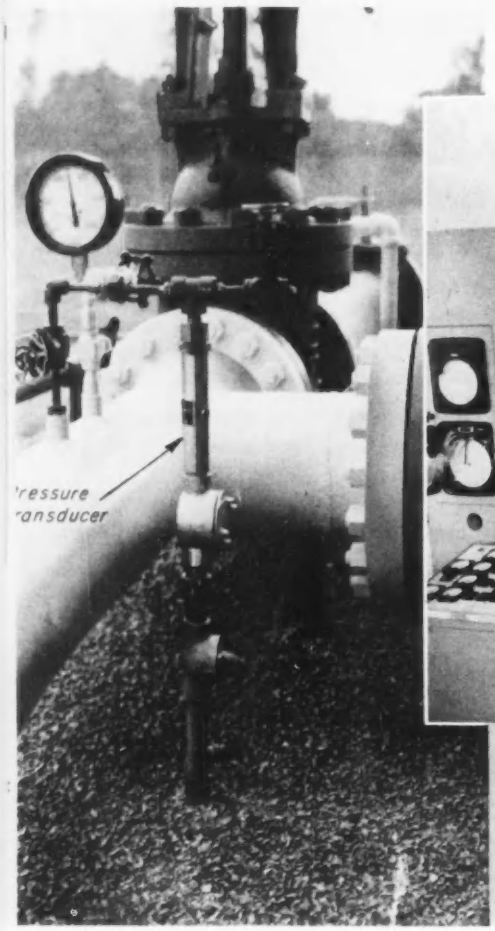
Unbonded-Gage Pressure Transducers

The pressure transducers described so far are those using the bonded wire resistance strain gage. The unbonded gage unit is also available in a variety of factory-built assemblies. Fig. 15 shows a Statham pressure transducer with the case removed. As described, this type unit consists of a frame and an armature that moves with respect to the frame. The arrangement of the strain filaments on pins mounted on the armature and frame is visible in Fig. 15. A trimmer resistor (not shown) is placed in series with one of the bridge filaments and used to equalize the resistance of the four gages in the bridge.

Because the gage filaments are contained within the instrument, they are fully protected at all times from mechanical injury. Being independent of the properties of the body under test, calibration is fixed and universal. Likewise, independence of test-body properties permits straining the gage filaments almost to the limit of their yield points. This permits wide range and is a feature of importance from the safety viewpoint. The complete symmetry of both mechanical and electrical components is also an important factor both in maintenance of calibration and in minimizing temperature errors. The construction lends itself to many combinations of element characteristics which, in turn, permit building gages of a great variety of sensitivities, ranges and natural frequencies.

In the Statham unit, pressure is converted to force by a flexible metallic bellows for the range from zero to 50 psi. The bellows isolates the gage measuring elements from the fluid under pressure, yet at the same time transmits the force to the gage armature.

At pressures above 50 psi, diaphragms are used instead of metallic bellows. These diaphragms are actually rigid disks of great strength, which represent a safety factor far in excess of normal engineering practice. In this case, diaphragm characteristics govern gage response (the diaphragm in Fig. 15 has a range of zero to 750 psi). Diaphragm materials are selected and treated for maximum stability and dimensions held within close tolerances. In addition to their use for measuring normal static pressures, these units are available for the measurement of differential and absolute pressures.



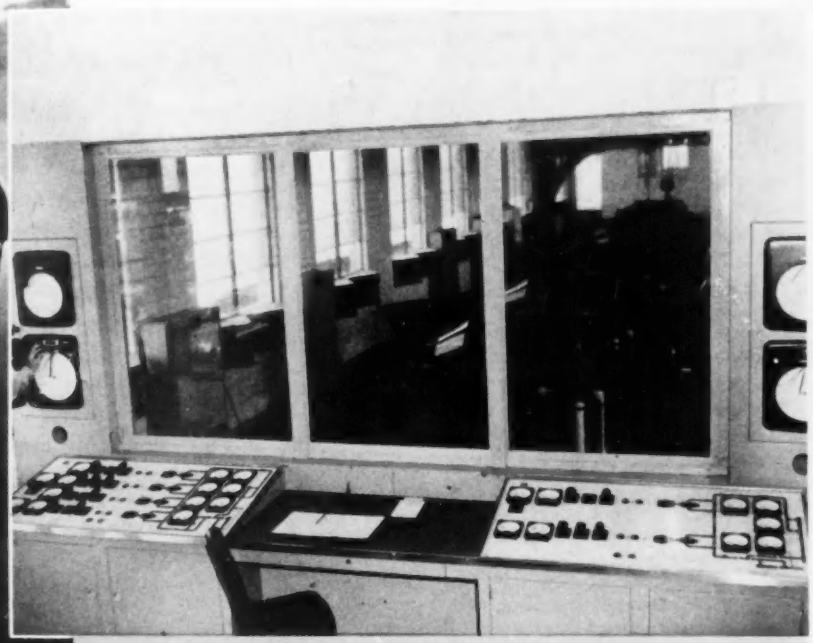


Fig. 16 (Left)—Monitoring of fluid pressures at key points in an elaborate piping system is done with Baldwin pressure transducers.
Plantation Pipe Line Company

Fig. 17 (Above)—Signals from pressure transducers in two piping systems register on meters in desk consoles. Recorders on wall plot pressures for various transducer stations. Plantation Pipe Line Company

Applications of Strain Gage Pressure Transducers

The Plantation Pipe Line Company of Athens, Ga., in cooperation with Baldwin-Lima-Hamilton and Ruge de Forest has developed a dependable electrical system for transmitting fluid pressures from various points in station piping to the control room.

The original experimental installation consisted of five meters to indicate station and pump suction; intermediate, pump discharge and outbound line pressures; five strain gage pressure cells mounted at various points on the piping and a power supply.

The meters, calibrated directly in terms of psi, were connected to the output of strain gage bridges in the pressure cells. By placing a fixed resistance in parallel with one leg of the bridge, the circuit was unbalanced by a fixed value corresponding to a known calibration pressure redlined on the instrument scale. The output of the cell being linear with respect to pressure, calibration at only one point on the scale was necessary.

One of the transducer installations is shown in Fig. 16. The valving is arranged to permit removal of pressure during the calibration referred to above, and if desired, a dead weight test can also be applied to the cell without removing it from the line.

Control of suction and discharge pressures presented another use for strain gage transducers as measuring elements. In this case, the bridge unbalance signal was converted to a proportional air pressure by Foxboro pneumatic pressure transmitters. A receiver-recorder in the control room recorded the pressure and controlled low suction and high discharge.

As a result of highly satisfactory performance obtained during 18 months from the experimental installation, Plantation has included similar equipment in the design of several other pumping stations. The new system differs from the original installation in that it operates on a-c instead of d-c. This change resulted in freedom from vacuum tubes in the main power supply and allowed the use of a more durable type of indicating meter. However, individual amplifiers are necessary in the output circuit of each pressure cell to drive the meter.

On the front of each amplifier are three controls and a selector switch. The "Resistance Balance" and "Capacity Balance" controls are for setting the zero of the pressure channel and for balancing out any in-phase and out-of-phase signal voltages present with zero pressure on the cell in the "operate" position. The "Calibrate-Adjust" position is set with dead weight calibration so that when the selector switch is thrown to the "Calibrate" position, an electrical signal is generated which is identical to that produced by a pressure of seven-tenths rated capacity of the transducer. Each meter is red-lined at seven-tenths of its scale and a calibration potentiometer is located in the control desk to bring the needle to the red line. It is not nec-

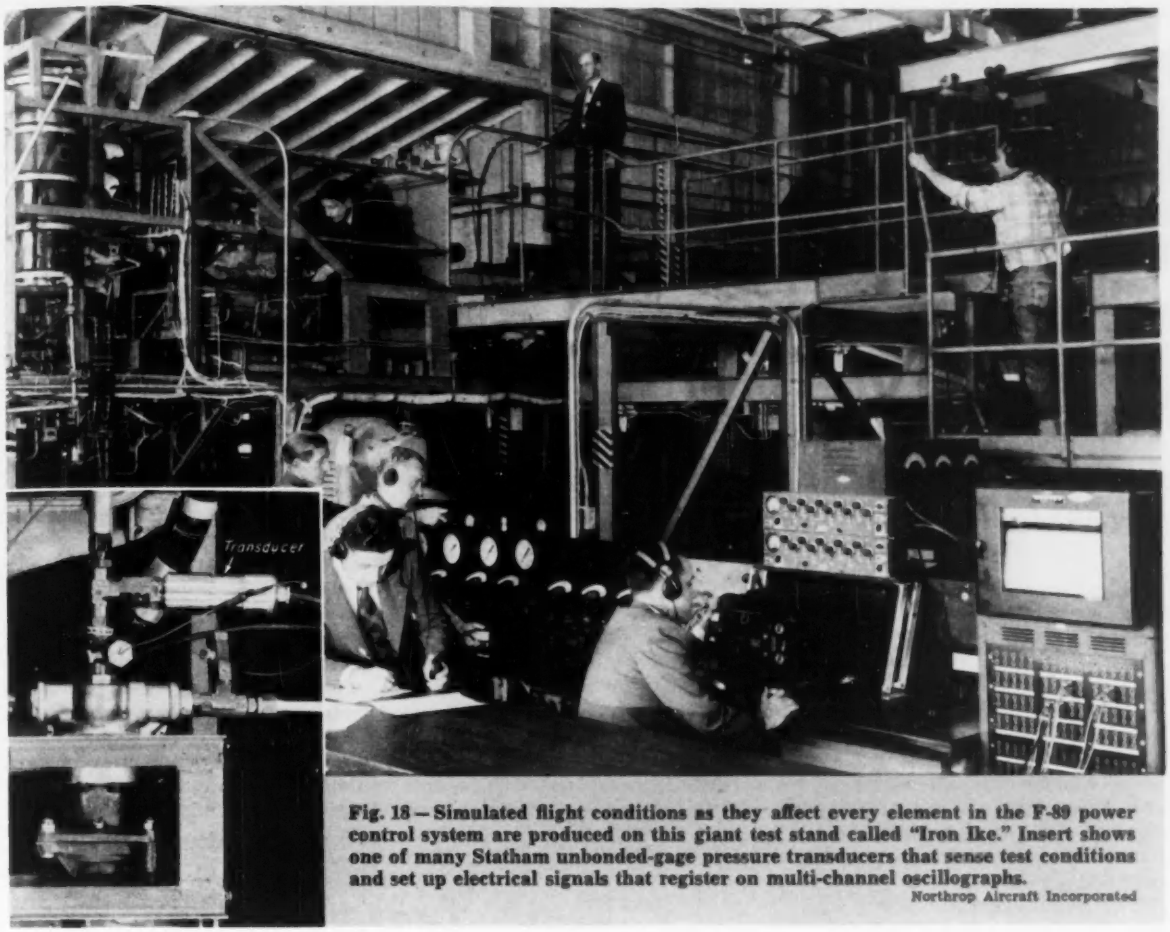


Fig. 18 – Simulated flight conditions as they affect every element in the F-89 power control system are produced on this giant test stand called "Iron Ike." Insert shows one of many Statham unbonded-gage pressure transducers that sense test conditions and set up electrical signals that register on multi-channel oscillographs.
Northrop Aircraft Incorporated

essary to remove pressure from the cell to obtain an electrical calibration.

The control desk at the Silver Run Station is shown in Fig. 17. Two pipe lines are controlled from this desk – an 18-in. line from the left half of the console and a 12-in. line from the right half. The meters are standard 5v a-c rectifier voltmeters with scales graduated in terms of psi. Pressure capacities range from 600 to 1,500 lb per square inch.

Among the advantages of this system are lower maintenance costs; increased accuracy over long periods of time; and elimination of frequent dead-weight calibrations, potential instrument piping leaks, and the hazard from fire or explosion when instrument lines carrying inflammable product are brought into control rooms.

POWER CONTROL SYSTEM MOCK-UP. Northrop Aircraft, Inc. has pioneered the development of full power control systems for aircraft. The N-9-M, one of the early Flying Wings built by Northrop, the giant B-35 YB-49 and YRB-49A Flying Wings, and the X-4 research airplanes were so equipped. When this same company developed the twin-jet F-89 Scorpion, this type control was again specified.

Every detail of the power control system used in the F-89 has been carefully reproduced in a giant test stand. Constructed on a structural steel network that has given the test stand its name of "Iron Ike," it contains all the mechanical, electrical and hydraulic components that go into a complete airplane control system. Every valve, pump, instrument, regulator and piece of tubing has been incorporated.

All the elements of flight from take-off to let-down can be simulated, recorded and analyzed by this test stand. Fig. 18 shows a general view of the facility with the control center in the foreground. The instruments record temperatures, pressures, response times and control positions registered by "Iron Ike" during a simulated flight.

A typical installation of a Statham P10 unbonded gage pressure transducer tee-ed into the discharge of one of the hydraulic pumps on "Iron Ike" is shown in the lower corner of Fig. 18. This unit measures the transient pressure effects and transmits an electrical signal proportional to the instantaneous pressure to a multi-channel oscillograph. In this way, the pressure history of various parts of the system can be accurately recorded in relation to the associated events in the system.

ROCKET ENGINE TESTING. The field of rocket testing presents some of the most difficult of pressure measurement problems to the instrument engineer. Standard industrial pressure measuring equipment of the Bourdon tube type is inadequate for this application because most test runs last only a fraction of a second and rarely exceed several minutes. During this short period, complete information relative to significant pressures throughout the system must be recorded, and, therefore, high frequency recording of pressures has

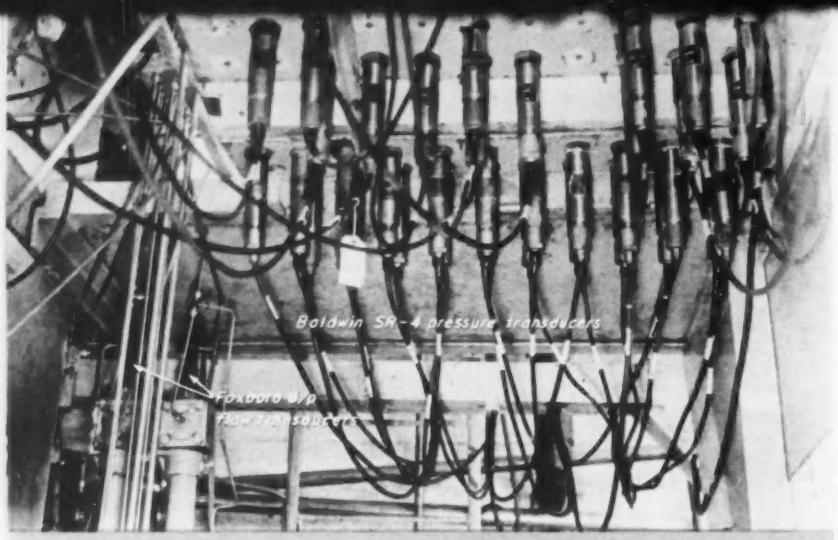


Fig. 19 – Rocket engine test stand has both pressure and flow transducers. These units, which cover several different ranges, actuate multi-channel moving-mirror and potentiometer type recorders in remote control room. M. W. Kellogg Company

become extremely important in studying reaction or combustion phenomena.

One of M. W. Kellogg's rocket engine test installations is shown in Fig. 19. The pressure transducers cover several different ranges, and are connected by four-conductor shielded cable to a remote control room. Here, Consolidated recording oscillographs register a complete picture of the high frequency pressure fluctuations occurring during tests. Sequential electrical operations and other variables are also recorded for analysis and study. In addition to the high frequency recorders, a group of Leeds & Northrup and Brown Instrument Co. strip-chart recorders calibrated in psi is also used. These instruments supply records for observation during tests, and for study immediately at the completion of a test (thus the waiting period necessary for the development of the oscillograph records is avoided). They also record to high accuracy the steady-state operating pressures of the units under test. The records obtained are subsequently analyzed to calculate the performance efficiency of the test item.

Several advantages are derived from the use of strain gage pressure transducers in rocket engine testing: (1) The direct-connected transducer and electrical transmission obviate the need for bringing into control rooms high pressure hydraulic lines that contain highly corrosive, toxic or inflammable fluids; (2) sealing fluids to protect instruments from contact with corrosive or dangerous fluids are no longer required because pressure transducers can be designed for direct contact with such fluids; (3) the range of a pressure measuring channel can be changed by inserting a different transducer without rebuilding the recording equipment; (4) at any time, the complete measuring system can be electrically calibrated from the recorder without application of known pressures to the transducer, and (5) the strain gage pressure transducer is a stable and dependable measuring unit. It has been used in extremely corrosive atmospheres and liquids, subject to shocks from hydraulic hammer and high pressure oscillations, and found to retain its calibration throughout long periods of time.

Flow Transducers

There are many classifications of flow meters. Of those that incorporate strain gage transducers, the most generally used is the head meter wherein there is variable differential head with constant area of flow passage.

Ordinary meters of this type consist of at least two parts; (1) a line restriction, or primary device, which alters the velocity of the fluid stream and produces a differential pressure; and (2) a measuring element, which senses the differential pressure and translates it into flow units.

In the strain gage type of head meter, the design is such that the differential pressure stresses the gages and therefore produces an output signal proportional to the force acting on the strain gages. The electrical output signal is then indicated in flow units by a recording instrument as shown schematically in Fig. 20.

Both the bonded and unbonded gages are applicable to an installation of this type. The Foxboro d/p cell, Fig. 21, is a typical bonded-gage differential pressure sensing element. Here a flexure tube is fitted with strain gages and wired in the conventional manner to complete a Wheatstone bridge.

Pressures are applied at the high and low taps, and then to the diaphragm, which exerts a differential

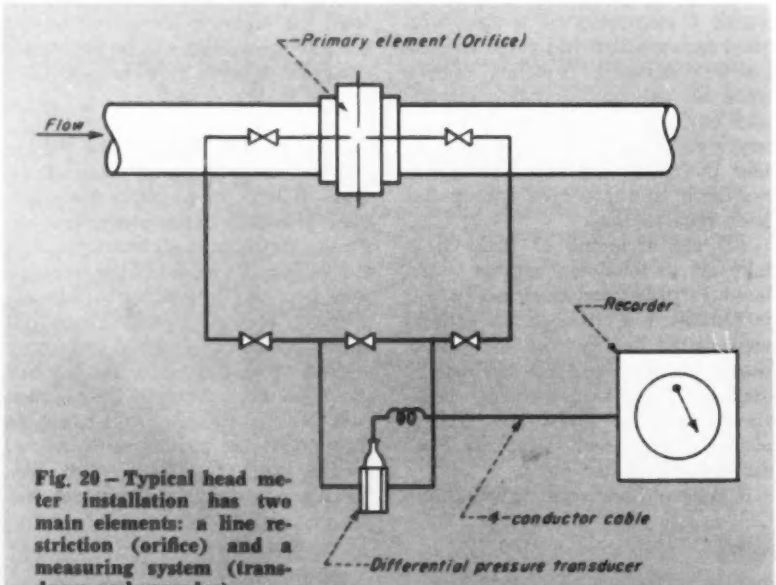


Fig. 20 – Typical head meter installation has two main elements: a line restriction (orifice) and a measuring system (transducer and recorder).

force on the flexure tube. The electrical system is similar to that previously described for the Bourdon tube type sensing element, thereby making the bridge output proportional to the differential pressure applied. The bridge can be excited with a maximum of 10 v a-c or d-c; and cell calibration is one millivolt output per volt input for full scale deflection at maximum rating.

When the d/p cell is connected to a Foxboro Dynalog recorder, both the internal and external bridge circuits are excited from the same power source, hence any variation in supply voltage cancels out. The excitation voltage is 5.5 v ± 0.5 v a-c when using a 1,000-cps voltage source.

The linearity of calibration for this strain gage flow meter system is within ± ¼ percent of range at 70 F. The Foxboro electrical d/p cell is rated at 1,500 psi static pressure with ranges available from zero to 100 in. H_2O through zero to 800 in. H_2O. The transducer will withstand a differential pressure of 1,500 psi without damage when applied to the upstream side. These cells can be furnished with Type 316 stainless steel diaphragm and body construction for corrosive service, and with other materials for specialized applications.

In addition to the diaphragm-type differential pressure transducer, bellows-actuated units are available from several manufacturers. In these units, the bellows is attached to the free end of a cantilever beam to which the strain gages are bonded in the form of a Wheatstone bridge.

Provisions are included for temperature compensation as in the Flader Teleflight differential pressure cell, Fig. 22, which has two opposing bellows for deflecting the cantilever beam. The bridge circuit is temperature compensated for the range from −65 to +165 F. To compensate for constant applied voltage across the bridge, a length of nickel or copper wire is placed in series with the input side of the bridge. Compensation for zero drift with temperature is achieved with a wire that uses the temperature coefficient of resistance in one leg of the bridge. Thermal expansion and contraction of the bellows is self-compensating in its effect on the bridge because of the two opposed bellows.

Production models of this transducer are limited to a zero shift of ¼ percent of full scale per 100-F change in temperature, and to a sensitivity change of 0.01 percent per degree F. They can be obtained with pressure ranges up to and including

Fig. 21 – The Foxboro d/p cell is a diaphragm-type bonded-gage differential pressure sensing element. Gages are mounted on flexure tube.

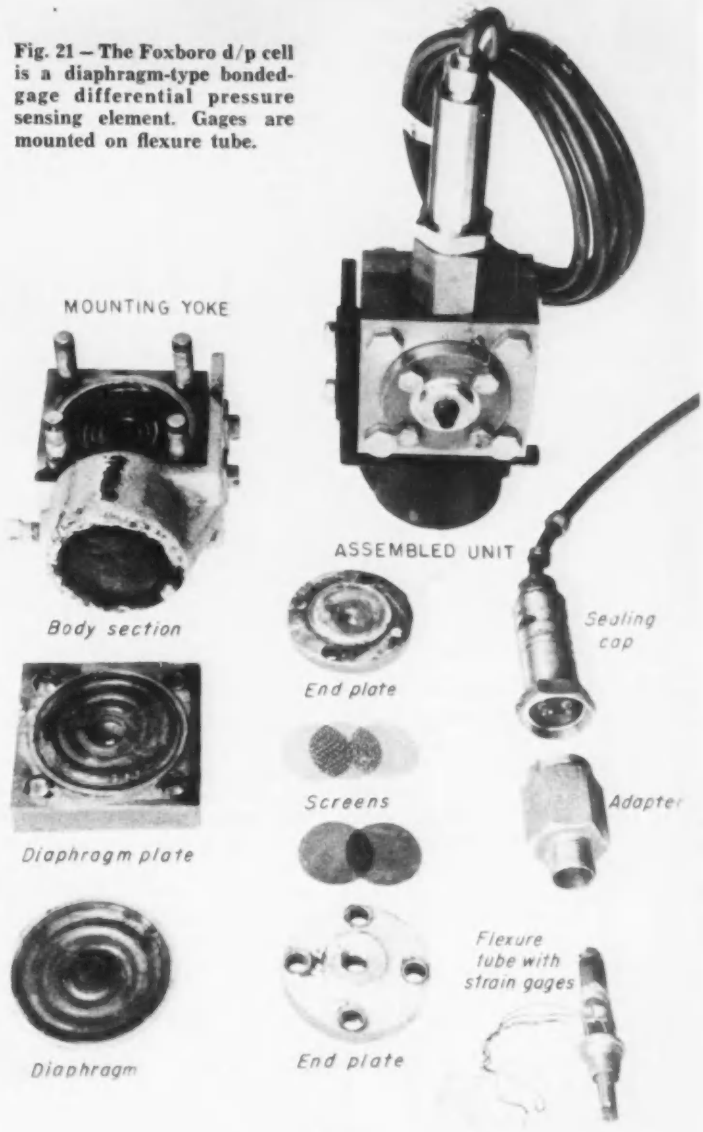
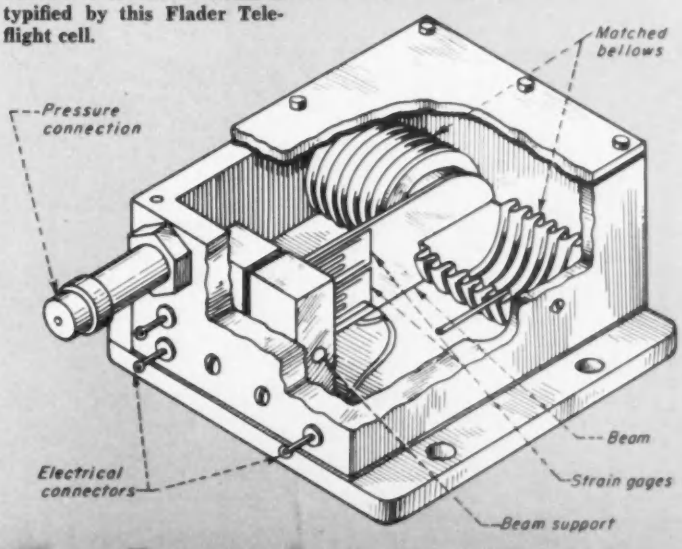


Fig. 22 – Bellows-actuated differential pressure transducers with gages bonded to cantilever beam is typified by this Flader Teleflight cell.



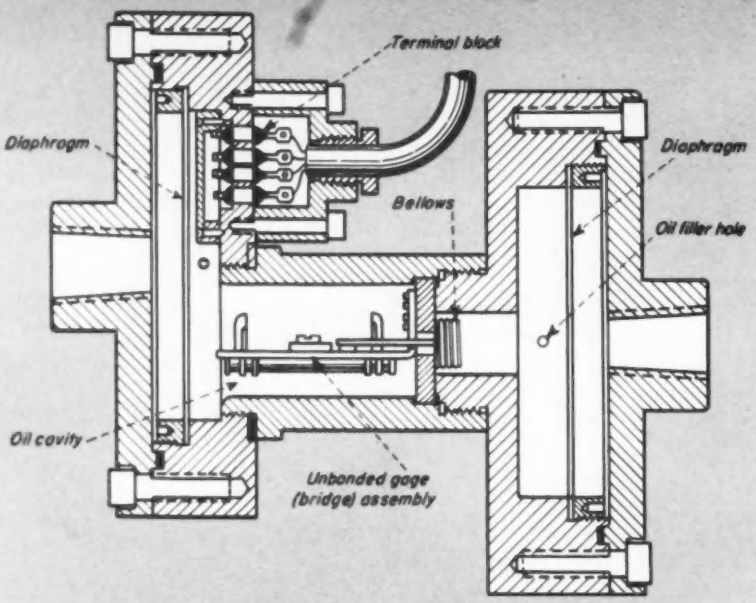


Fig. 23 – Non-corrosive fluids can be handled by this Statham unbonded-gage differential pressure transducer. Gage bridge is located in center cavity that is filled with oil.

zero to 50 psi. Typical dimensions are 1 by 1½ by 2 in. and weight is 3 to 6 oz. The units are applicable to steady state or dynamic measurements, and, depending upon the range, the pneumatic response is between 100 and 300 cycles per second.

The Baldwin differential pressure cell has the same general construction as the Flader unit. Calibration accuracy is within ± ¼ percent of full range for any point at 70 F. Recommended maximum operating temperature is 150 F, but the transducer will withstand 250 F continuously. Available ranges are from zero to ± 10 psi (with max line pressure of 50 psi) through zero to ± 20 psi (with max line pressure of 100 psi).

The Trans-sonics Inc. differential pressure cell has only one bellows at the free end of the cantilever beam. Differential pressure is thus measured across the single bellows directly. Ranges available are from zero to 10 psi through zero to 500 lb per sq inch.

The bonded gages are treated with special coatings so that neither their electrical resistance nor resistance to ground is influenced by exposure to moisture or vapors. Use of this transducer is limited to flow mediums that do not attack the gage coatings.

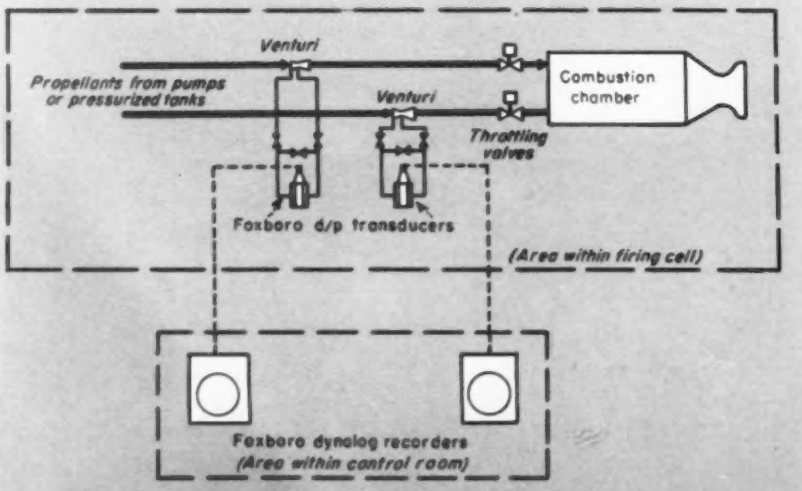


Fig. 24 – Fast-response system for measuring propellant flow in rocket engine test has Foxboro d/p transducers and Dynalog recorder with quick-disconnect venturis to vary flow range.

Unbonded strain gage differential pressure transducers for flow measurement are made by Statham Laboratories with the strain-sensitive element assembled as a full bridge. The units are designed to measure the difference between two pressures applied in operation, and can be supplied for use in both corrosive and non-corrosive service.

The type of construction depends upon the range and service. To produce an instrument of any particular full-scale range, a bellows or diaphragm is chosen on the basis of characteristics that cause the armature within the instrument to be displaced about 0.0015 in. when full-scale pressure is applied. A Statham gage of suitable electrical characteristics is then assembled within a structure that has provision for supporting the bellows or diaphragm chosen.

For the usual ranges of differential pressures required for measuring flow, Statham offers transducers that are sensitive to 0.05 psi full scale for non-corrosive gases with maximum line pressures of 15 psi. Other ranges for this service are available up to 40 psi differential and 50 psi line pressure.

For non-corrosive fluids, oil filled units, Fig. 23, are available with Type 416 stainless steep caps and isolating diaphragms made of neoprene or other special materials. The unbonded gage bridge is located in the oil cavity and the diaphragms prevent contact with the flow medium. Ranges are available from zero to one psi through zero to 40 psi for line pressures to 500, 1,500 or 2,000 psi. A model is also available for line pressures to 10,000 psi for ranges from zero to one psi through zero to 5,000 lb per sq inch.

Transducers of the same design are available for corrosive service except that the materials exposed to the flow medium are as required for the service.

The natural frequency of the units depends upon the construction used, and is usually from 350 to 1,700 cps, the higher ranges, generally having the higher natural frequencies.

Accuracy and linearity are one percent of full scale, and the resolution 0.1 percent of full scale, or better. Operating temperature limits are from −65 to +200 F. Input current can be alternating or direct, and a wide range of bridge resistances are available.

Either the bonded strain gage or the unbonded strain gage type of differential pressure transducer is suitable for operation with any of the in-

strumentation described earlier in this article. They have advantages over the mercury manometer type of instrument in the recording of high speed transient flow phenomena for study or analysis. Measurement of corrosive liquids can be obtained without the use of sealing fluids, and because of hermetic sealing, long life can be expected in corrosive atmospheres.

The small mass and weight of these transducers reduces the cost of installation and usually permits connection directly at the primary element without recourse to long connecting piping. Electrical operation permits remote transmission over relatively long distances.

The extremely small displacement required of the flow medium to obtain full-scale output of the transducers is an advantage over other types of flow measuring devices, as there is little tendency to pump sediment or foreign materials into the pressure measuring chambers. The lack of moving parts, pressure-tight bearings, linkages or pneumatic pilot devices reduces maintenance.

Typical Application of Flow Transducers

Referring again to the M. W. Kellogg rocket engine test installation, one of the most important variables required to determine engine performance is the accurate measurement of the flow propellants to the combustion chamber.

Many and varied are the problems attendant to obtaining this measurement. Firing from a few seconds duration to several minutes requires an extremely rapid instrument response. Propellants in use, such as concentrated nitric acid, ammonia and hydrogen peroxide require the use of special materials and equipment designs to withstand corrosive operating conditions for long periods. Extremely fast operation of throttling and shut-off valves requires high-speed tracking from the measuring instrument and the ability to withstand pressure peaks, "water-hammer" effects and flow throughout the ranges of operation.

Positioning of the recording instrument with relation to the location of the measuring element therefore requires some means of remote transmission, which obviates the need for high-pressure lines carrying propellants in the vicinity of operating personnel. Ease of changing the range of flow rate measurement is also of particular importance in meeting the requirements of rocket engine development tests.

The Kellogg Company has found the Foxboro resistance strain gage differential pressure sensing element and Dynalog recorder meet the requirements just mentioned. This flow measuring system is shown schematically in Fig. 24, along with two venturis which are used as the primary elements. These are designed with quick-disconnect fittings and can be changed in a few minutes to obtain a new flow range.

An installation of two Foxboro flow transducers can be seen in the lower left foreground of Fig. 19. The Dynalog circular-chart recorder is located on the instrument panel in the control room.

Weight Transducers

Measurement of weight and machine or mechanical loads has proven a fertile field for the application of strain gage transducers. No longer is it necessary to use the cumbersome systems of levers, pivots and bearings of conventional scales. Small, compact units in hermetically-sealed cases and without moving parts are now available for use in a wide range of applications for either static or dynamic operation. These units are designed around both the bonded and unbonded strain gages, although the majority of applications call for the bonded-gage type.

A schematic drawing of a typical bonded-gage load measuring trans-

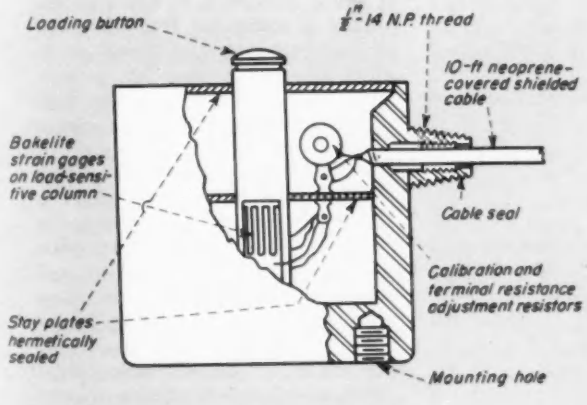


Fig. 25 – Bonded gage load transducer made by Baldwin is actuated by deformation of load-sensitive column to which gages are attached.

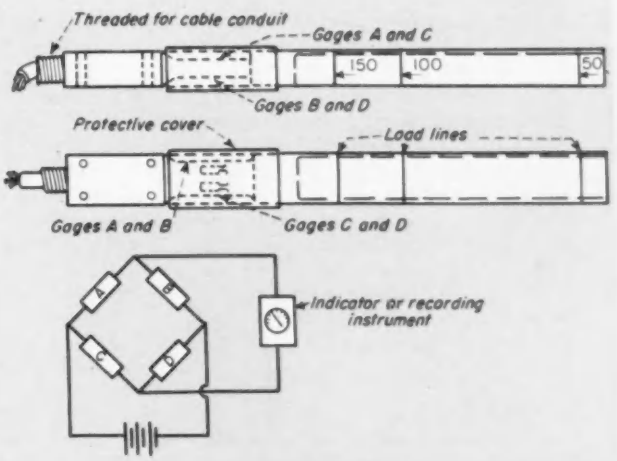


Fig. 26 – Load-beam weight transducer of Baldwin design consists of a cantilever-mounted bar with strain gages bonded adjacent to the fixed end.

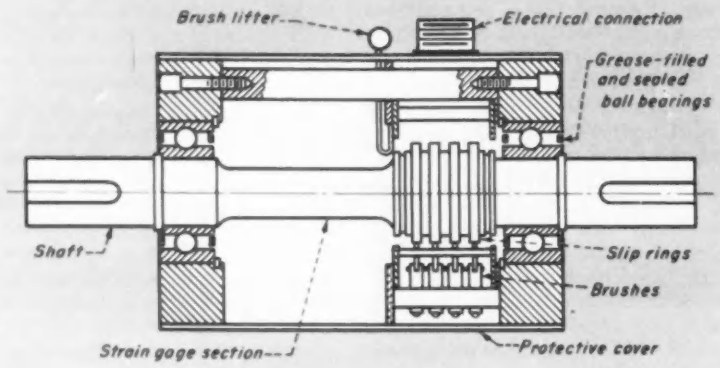


Fig. 27 – Model A torque transducer, another in the Baldwin line, is obtainable in eight standard capacities from 100 to 30,000 lb.-in.

ducer is shown in Fig. 25. Operation is based on obtaining an electrical signal from the stress induced in the strain gages as a result of a deformation in the load column. The gages are located on opposite sides of the column in so-called "back-to-back" position, with two gages mounted to pick up the axial strain and two others positioned at right angles. The latter are strained only in lateral contraction in accordance with Poisson's ratio. With this arrangement, active gages are used in all four arms of the Wheatstone bridge, thereby greatly increasing the bridge output. Since any change in dimensions due to ambient temperature affects all gages equally, only a force acting along the axis of the load column affects the bridge circuit.

By providing suitable attachments, this type transducer functions equally well as a tension or compression load measuring device. Desired ranges are obtained by variations in the mass and design of the load column, and, in this way, standardization of the electrical portion of the measuring circuit is achieved. Thus, an instrument connected to a zero-to-100-lb. transducer can be used with a zero-to-50,000-lb transducer without change.

Forms of Weight Transducers

Weight transducers of the bonded-gage type are supplied in various forms. The load beam consists of a metal bar mounted as a cantilever beam with strain gages bonded adjacent to the fixed end, as in Fig. 26. This transducer has been used in a special torquemeter designed to measure automobile steering wheel torque; in cradled dynamometers; in a line of industrial centrifuges to control rate of feed; and as a deflection gage. It is also widely used in aircraft for wind-tunnel studies of hinge moments, elevators and rudders.

The load beam itself is available in many types and sizes. The range of the smallest model in common use is zero to 0.5 lb; of the largest, zero to 1,000 lb. Ranges above and below these limits are entirely practicable.

The dimensions of load beams can be varied within wide limits in accordance with the requirements of an application. The unit shown in Fig. 25 has a maximum range of 150 lb and a length of 16¾ in.; yet beams have been built with a maximum capacity of 50 lb and a length of only 1 inch.

The *compression-type load cell*, Fig. 25, is used most extensively in tank, platform, conveyor, hopper and similar weighing. In these applications, the load cell is used as a supporting member for all or a portion of the weight of the container. The load to be measured can be carried by a single cell or distributed over several cells. In the latter case, the responses of the various cells can be automatically totalized as a single reading.

Ranges available include zero to 2,000, 5,000, 10,000, 20,000 and 50,000 lb. Calibration accuracy is within ± ¼ percent of full range at any point from zero to 100 percent of capacity. Physical dimensions of 2,000 to 10,000 lb cells are: overall height, 3¾ in.; diameter, 3⅜ in. For cells of 20,000 to 50,000 lb capacities, the overall height is 5¼ in. and the diameter 4 inches.

As stated, the *tension type load cell* is essentially the same as the compression unit except for the addition of means for attaching a tension link. Thus, it is particularly adapted for crane weighing, thrust and drag force measurements, and suspension load checks. Ranges and accuracy are the same as for the compression load cell.

A combination-load unit is also available. This is equipped with fittings that permit its use either as a tension or compression member.

The *torque transducer pickup* has an elastic member, usually in the form of a short shaft, to which strain gages are bonded. In a shaft subjected to torque, shear forces lie normal to and along the axis, with tension and compression components at 45 deg. Since wire gages measure only tension and compression, four gages are so placed along these 45-deg components as to measure torque or twist in terms of tension and compression. The gages are positioned and connected into a bridge circuit so as to cancel the effects of bending and thrust strains, while adding the effects of torsional strains. The relation between bridge unbalance and torsional strain is exactly linear.

Torque pickups have been built for shafts from ¼ to 18 in. in diameter; for zero rpm (to measure reaction torque) to 15,000 rpm; and from 10 oz-in. to 750,000 lb-ft capacity.

Standard models as produced by Baldwin-Lima-Hamilton are available in two types. Model A. Fig. 27, in which the brush or slip ring assembly is suspended from the shaft by ball bearings; and Model B, in which the brush assembly is supported on a pedestal, machine base or other rigid mounting in proper relation to the shaft.

Model A is a self-contained pickup and easier to set up. Model B is shorter in length, will operate at higher speeds and temperatures (due to the absence of ball bearings), and has an economy in that the same brush assembly can be used on two or more different sized pickups in case they are to be used interchangeably.

Both models are obtainable in eight standard capacities from 100 to 30,000 lb-in. full scale. Pickups are also available with kilogram-centimeter ratings which are numerically the same as the pound-inch ratings.

Calibration accuracy is within ±¼ percent of full range in either direction at any point from zero to 100

percent of capacity. The units are temperature compensated with a recommended temperature limit of 140 F for the Model A and 170 F for the Model B pickup.

Operating speed of the Model A pickup is limited by permissible bearing speeds. This limit is 7,000 rpm in the lower ranges, and 5,000 rpm in the higher ranges. For the Model B pickup, the limitation is slip ring surface speed. Under optimum conditions, surface speed can go to about 7,500 ft/min, but since these conditions are difficult to attain, 5,000 ft/min is the nominal limit. Recommended maximum speed for torque units is 10,000 rpm in ranges from 100 to 1,000 lb-in., 12,000 rpm in ranges from 2,000 to 5,000 lb-in. and 7,000 rpm in ranges from 12,000 to 30,000 lb-inches.

Unbonded-Gage Weight Transducer

As has been true in the other fields of measurement, the unbonded strain gage is also utilized in transducers for the measurement of weight, load or torque. These units are manufactured by Statham Laboratories in several different designs that bracket many scale ranges.

The strain-sensitive element of the Statham gage is, as stated, the special frame, the armature and four sets of resistance wire elements. For the lower force ranges, the resistance wire itself supplies the elastic stiffness in the transducer. In this way, forces as small as fractions of an ounce can be measured and recorded. These low-range units are adaptable to such applications as gyro pickoffs, low-range weighing devices, measurement of torque in test stands, stress-strain diagrams of textile fibres and measurement of cantilever deflections.

Transducers for measuring the smallest forces are available in ranges from ± 0.15 to ± 5.5 oz full scale, with a displacement range of ± 0.015 in. A second group of transducers covers the ranges from ± 1.5 to ± 48 oz full scale, with a displacement range of ± 0.0015 in. These two groups are specified with an accuracy and linearity of one percent full scale or better, and a resolution of 0.1 percent or better.

A third group is available with ranges of 25 to 500 lb for the electrical measurement of tension, compression, or tension and compression. These ranges are particularly suitable in making dynamic recordings of force during stress-strain determinations, breaking-strength tests, ordinary load measurements, and in

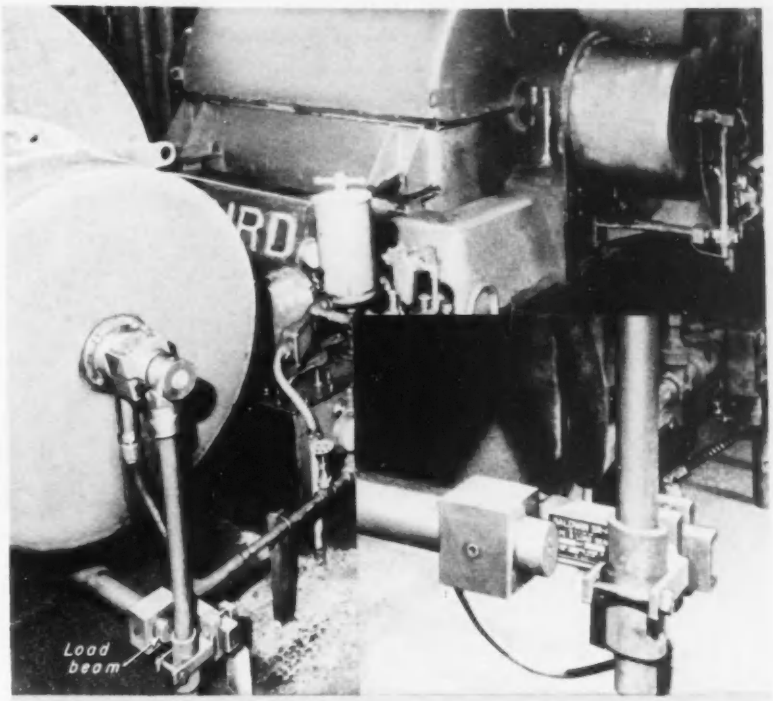


Fig. 28 – The flow rate of coal moving into an automatic separator is controlled by a system composed of an SR-4 load beam for measuring torque and a Foxboro recorder. H. C. Frick Company

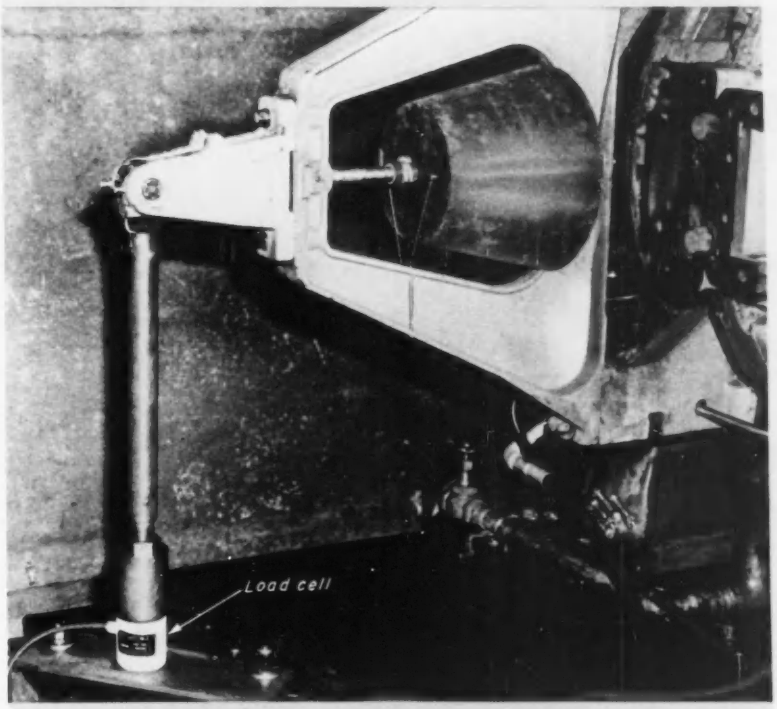


Fig. 29 – Dynamometer loads developed during tests on aircraft reciprocating engines are measured with SR-4 compression type-load cell at lower left. Wright Aeronautical Div., Curtiss-Wright Corporation

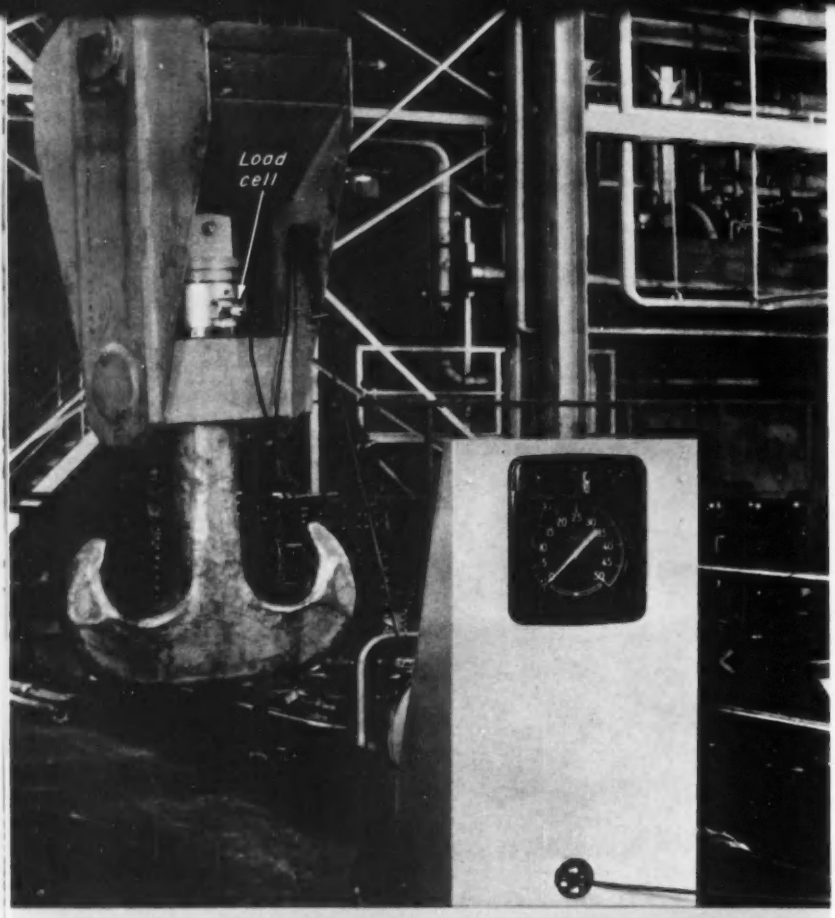
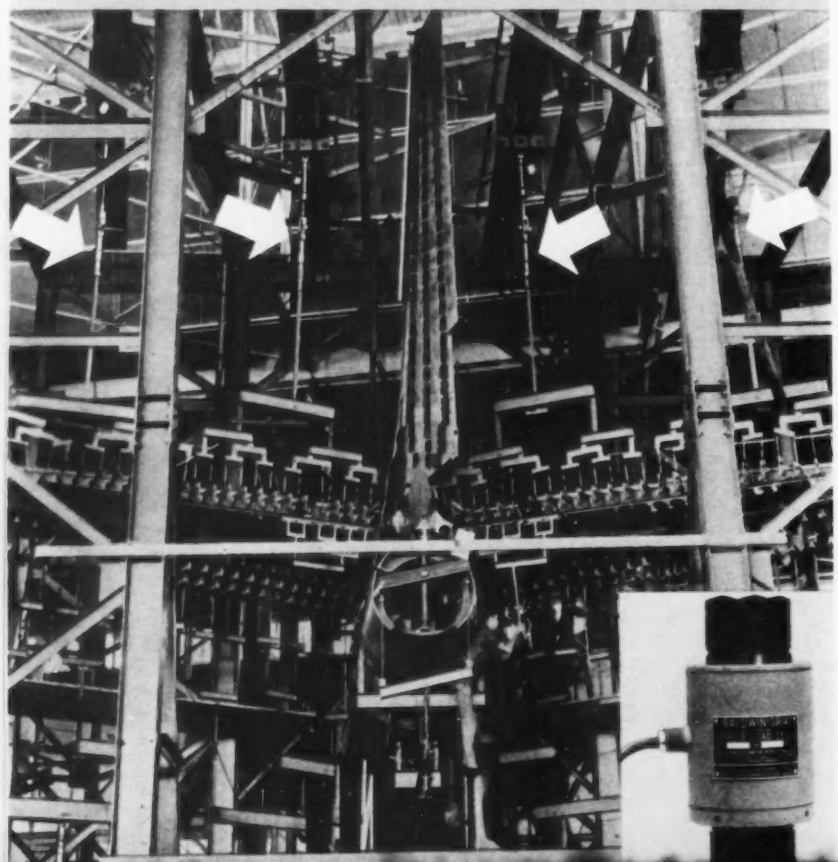


Fig. 30 – 300,000-lb compression load cell is permanent part of crane hook. GE has found this to be a simple method of weighing transformers.
General Electric Company

Fig. 31 – Thirty-two SR-4 tension-type load cells (four shown) were used as links in load harnesses for measuring wing and tail loads in the B-47 bomber. Cells were in series with hydraulic rams pressured by jacks. Boeing Airplane Company



many other instances where electrical indication or recording is desirable. Accuracy and linearity of this group is one-half percent full scale with a resolution of 0.1 percent or better.

All of these transducers are extremely small and compact, ranging in overall dimensions from $2\frac{1}{4}$ by $1\frac{3}{8}$ by $\frac{35}{64}$ in. for the first group to $4\frac{1}{16}$ by $1\frac{23}{32}$ by $1\frac{23}{32}$ in. for the third group. Weights per transducer are: group one, $1\frac{3}{8}$ oz; group two, $2\frac{1}{2}$ oz; and group three, $2\frac{3}{4}$ pounds.

For the measurement of large forces or weights, Statham incorporates their unbonded gage in both tension drawbars and proving rings. These units can be supplied in ranges from less than 100 lb to many thousands of pounds.

All of the Statham units are sealed against moisture and contaminants and will operate within temperature limits of approximately –65 to +200F. The units have high natural frequencies, and show no fatigue after many million cycles of operation in their full range of displacement.

The transducers manufactured by Baldwin or Statham for measuring load or torque are suitable for a-c or d-c operation, and will function with any of the instruments described in this article. Thus a continuous or periodic measurement of weight, force or torque with respect to time or operational activity can be recorded. Continuous chart records of equipment performance under actual operating conditions can be obtained for setting operational patterns as well as for analysis, study or future reference.

Weighing systems are available for recording exact weight on ticket, tape or on a ledger sheet. Control action can be arranged with any of the transducers in the form of electric on-off, high-low or proportioning action. Hydraulic or pneumatic control action can also be set up in various forms.

Applications of Weight and Load Transducers

The H. C. Frick Company uses eight automatically controlled separators to handle 300 tons of coal per hour in particle sizes up to ¼ inch. The load control system for each unit consists of a Baldwin SR-4 load beam and a Foxboro recorder controller. The torque required to operate each separator transmits a force against the load beam through a vertical arm extending down from one end of a horizontal shaft at the end of the machine. The arm is retained loosely

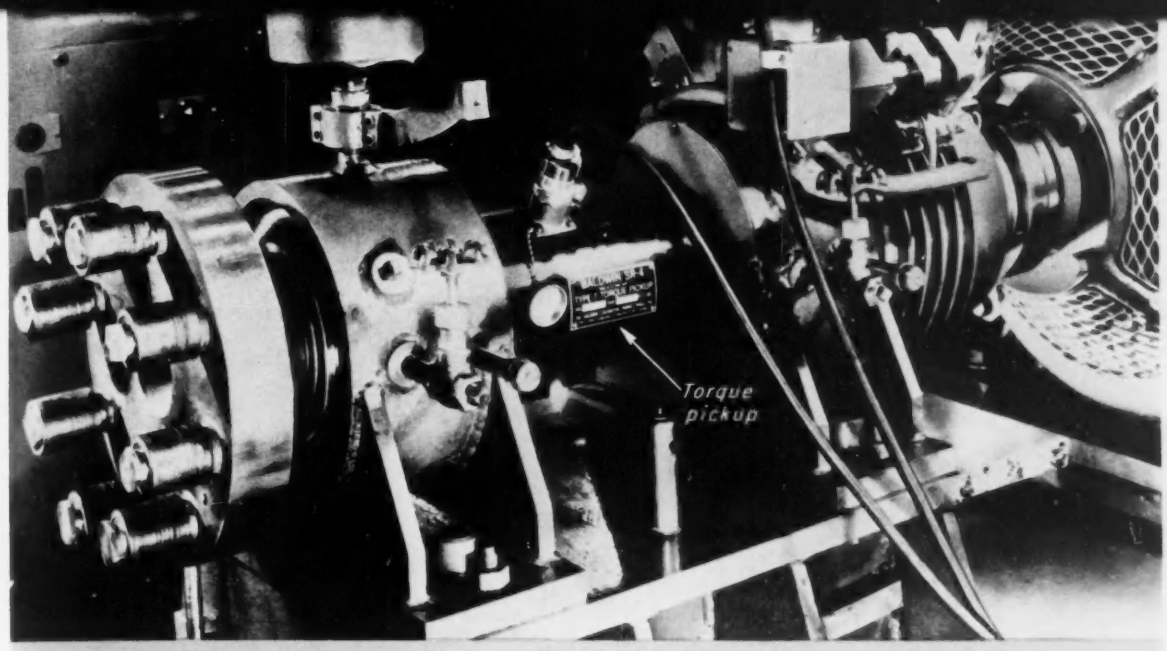


Fig. 32—The Baldwin Type T Model A torque pickup is the heart of a simple, yet accurate method of determining the horsepower input of centrifugal pumps. Allis-Chalmers Mfg. Company

by a clevis clamped on one end of the load beam, as shown in Fig. 28 and supported by a bracket extending from the base of the machine.

The signal to the control instrument is used to proportion the flow rate of material moving into a separator. If the load exceeds 15 percent above normal, the feed is cut off automatically until the machine has cleared itself. If the load continues to increase, not only is the feed cut off but the machine is stopped. Complete stoppage occurs if the torque load becomes zero, as when a shear pin breaks in the drive.

WEIGHING DYNAMOMETER LOADS. Dynamometer loads are weighed by an electronic system recently adopted at the Curtiss Wright Plant in Wood-Ridge, New Jersey. Fig. 29 shows a Baldwin SR-4 compression type load cell at the left under the column linked to the arm of a 3,000 hp cradle-type dynamometer used for full scale tests of aircraft reciprocating engines. SR-4 load cells have also been adopted at Wood-Ridge for measuring the thrust of turbo-jet engines.

ELECTRONIC CRANE SCALE. Strain gage compression load cells of 300,000 lb capacity are permanently installed in each of two crane hooks at GE's transformer plant.

The load cell in Fig. 30 occupies only 9 in. of head room. A portable weight indicator, accessory reels of electric cord for connection to the cell units and a power supply outlet are carried on a rubber-tired hand truck. The indicator has three scales: zero to 50 tons, 50 to 100 tons, and 100 to 150 tons.

When two cells are used together to lift a load, each is read independently, using a switch on the indicator to select the load cell to be read. Chief use of this weighing system is to determine the weights of transformers for shipping.

AIRCRAFT STRUCTURAL TESTS. Thirty-two Baldwin SR-4 tension load cells were used to measure loads at extreme points during recently-concluded structural tests of the B-47 Stratojet bomber. The four cells visible in Fig. 31 were used as links in the main trunk of several equalizing load harnesses for measuring wing and tail loads, and in other structural members for measuring fuselage, empennage, door and reaction loads totaling more than 700,000 pounds. All loads were read at a central point on two self-balancing indicators.

Most of the 32 cells were installed in series with hydraulic rams pressured by manually-operated jacks. The cells have capacities of 20,000, 50,000 and 100,000 pounds.

AUTOMATIC CONTROL OF DRYER ROLL LOAD. Closer automatic control in paper making, faster production, improved paper quality, and reduced costs have resulted from the application of a new type load meter to paper mill dryer rolls.

Installed on one of the world's largest combination felt and liner board machines, the Downington load meter has substantially improved the quality of control, thus improving thickness uniformity, tensile strength, density and finish of paper for U.S. Gypsum's Sheetrock wall board, Rocklath plaster board and gypsum sheathing board.

Realizing that it was difficult to maintain uniform nip pressures with existing weighing systems, the Downington Manufacturing Company developed a system incorporating standard Baldwin SR-4 tension type load cells. The cell permits direct measurement of roll load thus eliminating all pin and knife edge friction, eccentric and misalignment loads, friction of piston packing or glands, piston leakage, and the inaccuracies of ordinary Bourdon type gages.

TORQUE MEASUREMENT IN PUMP TESTING. To better the convenience and speed of performance measurements made in designing pumps, the Worthington Pump and Machinery Corporation has supplemented dynamometers with bonded strain gage torque measuring instrumentation. Coupled to the drive shaft, the Baldwin Type T Model B torque pickup provides an accurate and continual indication of torque and power delivered to the pump. A portable, self-contained in-

Fig. 33 – A continuous two-year record of twist in tape was made possible through the use of a Baldwin SR-4 torque pickup and a high-speed direct-writing oscillograph.

Greenfield Tap and Die Corp.

Fig. 34 – Extreme accuracy of this external comparator depends upon a special measuring element containing a strain gage bridge. Readings in range from 0.0001 to 0.00001 in. can be taken on amplifier scale. Brown & Sharpe Mfg. Company

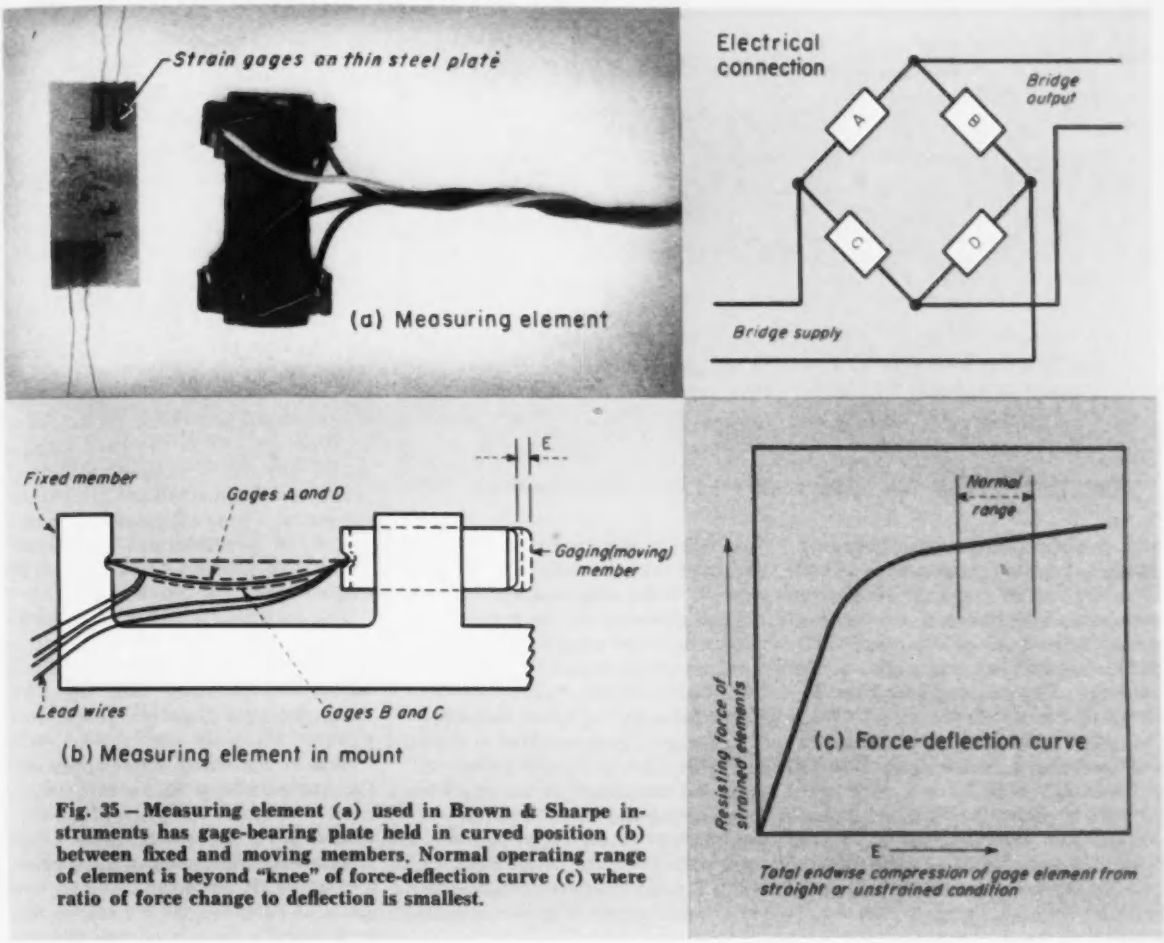


Fig. 35 – Measuring element (a) used in Brown & Sharpe instruments has gage-bearing plate held in curved position (b) between fixed and moving members. Normal operating range of element is beyond "knee" of force-deflection curve (c) where ratio of force change to deflection is smallest.

dicator calibrated in pound-feet is wired to the pickup.

A similar application of the Baldwin Type T Model A torque pickup is shown in Fig. 32. Allis-Chalmers Manufacturing Company uses this simple yet accurate test procedure for determining the horsepower input of centrifugal pumps. Formerly a calibrated motor was used.

MEASUREMENT OF TAPPING TORQUES. A novel method of producing continuous records of torque throughout a two-year tap torque testing program has given the Greenfield Tap and Die Corporation complete and accurate histories of tapping cycles.

Twist is measured by the Baldwin SR-4 Torquemeter shown in Fig. 33 and the varying tap torque recorded by a high-speed direct-writing oscillograph on a paper strip chart. These records are the basis for determining the effects of such design variables as rake and relief, as well as such operating conditions as speed, lubrication and rate of wear.

Displacement Transducers

Displacement can be measured manually with rules, tapes, dial gages and calipers, or automatically by pneumatic and electrical methods. It is in this latter group that the strain gage plays a useful and accurate part.

Transducers incorporating strain gages are available for measuring both linear and angular accelerations, linear displacement, velocity and vibration. In addition, strain gages are the heart of such measuring tools as extensometers (deflection indicators), external and internal comparators, various types of gaging equipment, inspecting and sorting machines and physical testing machines.

Bonded strain gages are the basis of a complete line of electronic dimension-measuring equipment made by the Brown & Sharpe Manufacturing Company of Providence, Rhode Island.

Requirements as set up by this company for the measuring element included high sensitivity, linearity, stability (freedom from drift), low operating pressure, freedom from internal thermal effects, a low spring constant and a simple yet sturdy design of small physical dimensions.

The external comparator illustrated in Fig. 34 provides a reliable means for taking external measurements electronically in units varying from 0.0001 to 0.00001 inch.

The measuring element in this comparator, Fig. 35(a) contains four bonded strain gages mounted on a thin tempered steel core 0.010 in. thick, ½ in. wide and 1⅜ in. long. As in other transducers, the gages are connected in the form of a bridge circuit.

The diagram, Fig. 35(b), shows

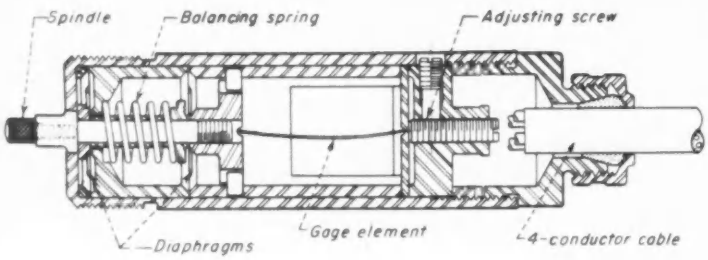


Fig. 36 – Cartridge-type displacement transducer can be screwed or clamped in position. Most of the energy exerted on gage element by the spindle is counterbalanced by the spring, leaving a small net force to be measured. Brown & Sharpe Mfg. Company

how the gage assembly is held in a curved position between a fixed member and a moving or gaging member. Movement of the gaging member compresses the gage unit endwise, causing a compressive strain on the two upper gages and tensile strain on the two lower gages. Thus, the gage assembly is, in effect, a slender column under a load sufficient to cause deflection. It is designed to operate in the region beyond the "knee" of the force-deflection curve, Fig. 35(c), where the ratio of force change to deflection is smallest.

As the gaging point of the comparator is deflected, the minute changes in the electrical resistance of the bridge circuit create voltage signals, which are amplified to operate the indicating meter. Line voltage fluctuations within the range from 105 to 125 v do not affect readings.

The gage-signal amplifier is shown in Fig. 34. The sensitivity potentiometer near the center of the panel has a graduated dial on which commonly used values of each graduation are scribed in decimals of an inch. The 5/32 in. wide graduations provide a total magnification of gage movement from 1,800 at minimum sensitivity to 18,000 at maximum sensitivity.

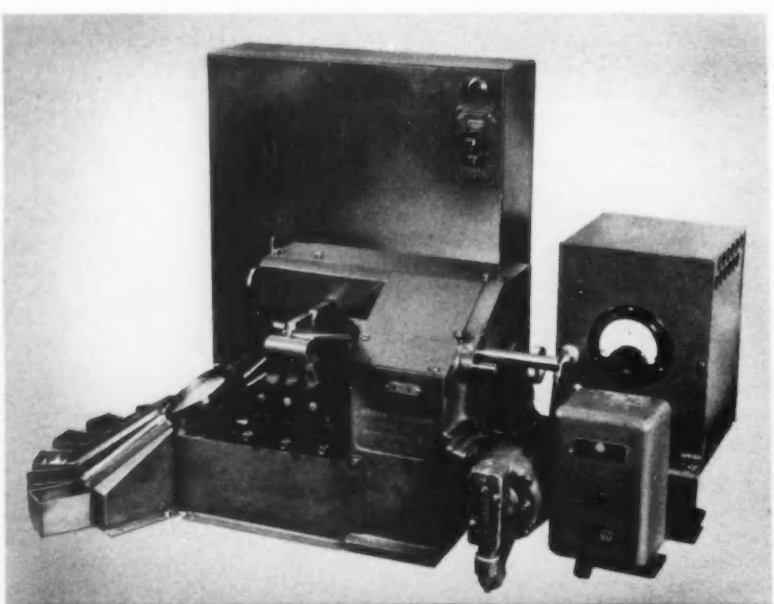


Fig. 37 – Three transducer cartridges and an amplifier are used in this machine for checking the taper of anti-friction bearing rollers and sorting these parts into six size categories. Brown & Sharpe Mfg. Company

Adaptations of Displacement Transducers

The following illustrations demonstrate some of the uses to which this displacement type strain gage unit has been applied. Many applications incorporate a general-purpose cartridge transducer, a sectional view of which appears in Fig. 36 with wiring omitted. The gage unit is acted upon directly by the measuring spindle which is supported by flexible diaphragms to eliminate friction and bearing looseness. Most of the force required to deflect the gage is balanced out by an opposing helical spring leaving a small net force to be measured. These components are enclosed in a cylindrical steel body having a diameter of 1¼ in. and an overall length of 5¼ inches.

The cartridge is easily clamped in position or can be screwed into a hole on the threads provided. Final adjustment is made with the zero balancing potentiometer in the amplifier.

One of the many applications for this transducer is in an instrument used to measure the pitch of helical-wound wire on flexible cable while it is moving. Variations in pitch cause a relative displacement of follower gears, in turn causing an arm to rise or fall and act on a cartridge indicator.

Another application is in special equipment for sorting parts into size categories for selective assembly. The particular machine shown in Fig. 37 checks tapered roller bearings for taper and sorts the parts into six size categories. Three cartridges and an amplifier are used. Sensitive instrument-type relays are tripped at predetermined current values of amplifier output, indirectly causing solenoid to position a chute and direct the part to the proper container.

These displacement-type transducers have the advantage of eliminating differences in measurement resulting from the human "touch" or "feel" because measurements have the same accuracy whether taken by one or several different operators. In addition only one gage block or master is needed to make a setting with these instruments. This is possible because of the true linear response of the measuring system with resulting accurate calibration of the scale.

Gaging fixtures that perform special functions and simplify taking measurements to extremely close limits can be developed. Such fix-

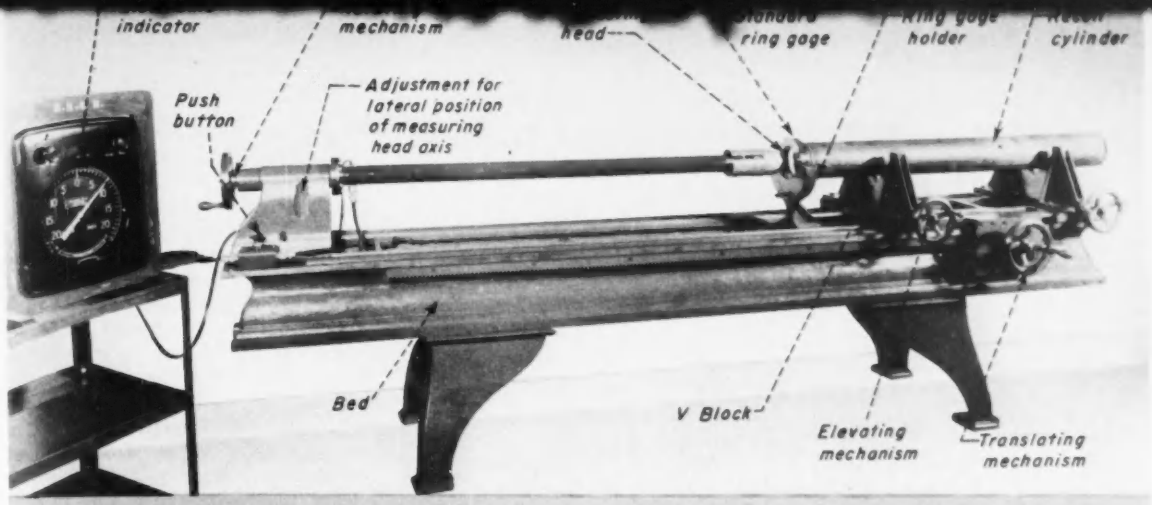


Fig. 38 – Measuring head on machine that measures inside diameters of a gun recoil cylinder has strain gages bonded to small cantilever beams. Intensity of gage signals determines whether ID of cylinder is "over" or "under" standard ring diameter. Watertown Arsenal

tures could be designed so that several instruments indicate simultaneously either as an average, combined or individual reading.

GUN RECOIL CYLINDER GAGING MACHINE. The gaging machine shown in Fig. 38 was built by Ruge-de-Forest Inc. of Cambridge, Mass. for measuring the inside diameters of a recoil cylinder to a guaranteed accuracy of better than ±0.0005 inch.

The cylinder rests in two V-blocks mounted on a translating carriage. The measuring head is made up of strain gages bonded to small cantilever beams that "feel" the inside diameter of the cylinder as it is moved along the bed of the machine. The head can be revolved by the rotating mechanism at the left end of the machine so as to check for ellipticity.

In operation, the measuring head first "feels" the standard ring gage mounted on the carriage, at which point the "over-under" indicator is set to read zero. The head then enters the cylinder and the indicator shows the "over" and "under" size from the standard ring diameter as the head is rotated through the bore. Each small division on the indicator is 0.005 in. and range is ± 0.023 inch.

The retracting mechanism prevents the nylon-tipped gage feelers from touching except at the instant a measurement is made. In this way, a two-microinch surface can be gaged without its being damaged.

TENSILE TESTING MACHINE. The Instron Engineering Corporation of Quincy, Mass. has incorporated bonded strain gage transducers in the measuring system of their tensile testing machine. The unit is built to measure accurately, over a wide range of conditions, the load-elongation properties of materials ranging from the finest single textile fibers to complex plastics and rubbers. It is also well suited for tear testing of fabrics and plastic films where the magnitude and rapid variations of loads are detected in a low-inertia system.

The tester, Fig. 39, has controls for operating the pulling jaws at the right and the recording instrument at the left. A typical strain gage load cell and bayonet coupling for the upper or fixed jaw are shown in the insert.

An electronic weighing system is used for detecting and recording the load applied to the sample under test. The primary measuring elements are the interchangeable load cells that provide four measuring ranges extending from ten grams full scale to 1,000 lb full scale in twenty steps.

Calibration of the cell is simply and easily performed through the use of weights. In addition, electrical adjustments are provided to compensate for variations in the weight of the different pulling jaws and for the weight of the sample itself.

Load variations produce electrical

Fig. 39 – Interchangeable load cells provide four measuring ranges from 10 grams full scale to 1,000 lb full scale in a tensile machine designed for testing load elongation properties of fibers, plastics and rubbers. Insert shows bayonet coupling and typical load cell. Instron Engineering Corporation

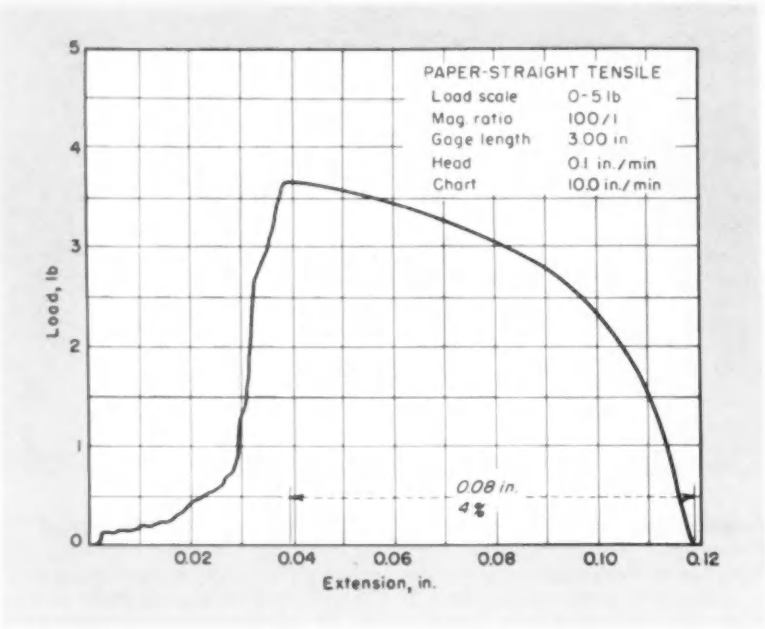


Fig. 40 – Tensile test of high-grade paper shows fibers are gradually pulled apart before rupture finally occurs. Instron Engineering Corporation

signals that are amplified to operate a high-speed graphic recorder. The chart of the recorder is synchronously driven at various speed ratios with respect to the pulling jaws so that the resulting trace is an accurate load-elongation curve of the material.

Typical of tests conducted on this equipment is the determination of the tensile characteristics for high-grade paper, a material of low extensibility requiring high magnification. Rupture, as shown in Fig. 40, does not take place at once, but, instead, the individual fibers are pulled apart gradually.

Unbonded-Gage Displacement Devices

The basic Statham transducer element as used in pressure, flow or weight applications is essentially a displacement measuring device. Furnished as such in a packaged unit, its range is to 0.003 inch, which, of course, can be extended with a suitable linkage or flexure system. The natural frequency for each unit can be set at a desired point in the range from 400 to 1,900 cps, depending upon the force range in ounces to obtain full displacement.

If a mass is attached to the armature of the basic Statham element, it becomes an acceleration, velocity or vibration displacement transducer. When the case is shaken, relative movement between the mass and case occurs, and the strain gage unit produces an electrical signal proportional to the displacement or velocity of the mass with respect to the case.

The construction of a Statham accelerometer is shown in Fig. 41. The mechanical system consists of an elastically suspended mass hinged at one end to a cantilever flexure plate. Four sets of resistance wire filaments connected as a bridge are strung above and below the mass and arranged to provide the elastic support for the mass. When the mass is displaced in a direction normal to the base, two sets of filaments are stretched, while the other two contract. Since the resistance of the filaments depends upon their lengths, the pairs of filaments are caused to change in resistance equally and oppositely. The case is usually filled with damping fluid after being evacuated and an expansion chamber with elastic diaphragm is provided to permit fluid volume change with temperature.

The natural frequency and range of the accelerometer is determined by the mass, and the elasticity of the strain filaments. Since the pickoff system in these accelerometers is sensitive to displacement, the electrical output is a linear function of the applied acceleration as long as the frequency of the applied acceleration is less than about half the natural frequency of the meter.

As the range of the accelerometer depends upon the weight attached to the armature, and the number and diameter of strain sensitive wires by which it is supported, a wide selection of ranges can be obtained. Accelerometers have been constructed with ranges as low as $\pm$ 0.5 G and as high as $\pm$ 1,000 G. Actually, it is possible to extend these limits almost indefinitely.

Statham accelerometers are made in a wide variety of designs for each of the many fields requiring instruments for measuring acceleration and vibration. The resistive nature of the balanced four-arm bridge of the unbonded strain gage type permits its use in either a-c or d-c circuits so that different types of recording or indicating systems can be adapted.

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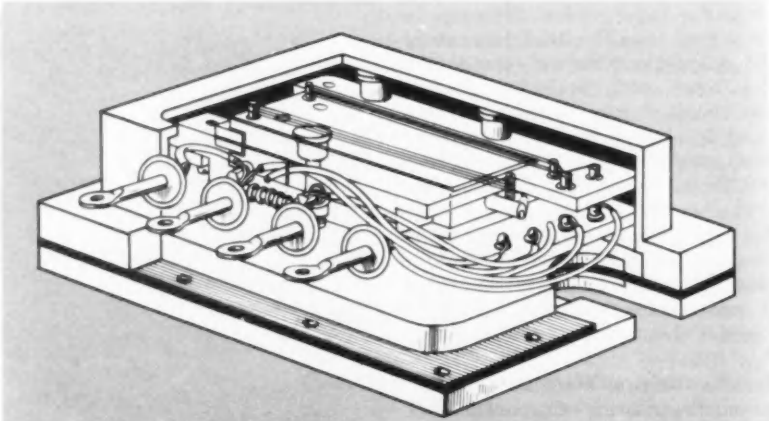
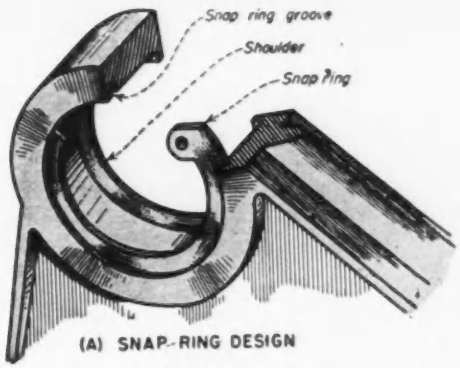
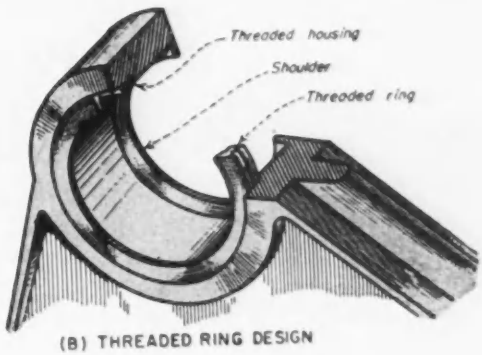


Fig. 41 – Statham accelerometer has a mass hinged at one end to a cantilever flexure plate. Four sets of filaments connected as a bridge above and below the mass are stretched or compressed when mass is displaced in a direction normal to the base.



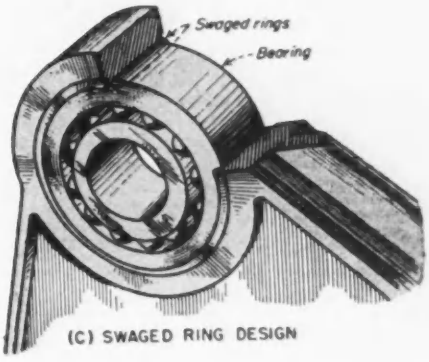
(A) SNAP-RING DESIGN

Fig. 1—Methods of bearing retention.



(B) THREADED RING DESIGN

Swaged Housing Ring Grooves to Retain Axial Thrust Bearings



(C) SWAGED RING DESIGN

Design criteria for retaining bearings in housings by means of a lip roll swaged around circumference of the housing bore. Results of an investigation that included press swaging, friction spin swaging, and roll swaging both ductile and notch sensitive materials.

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PROMPTED BY THE NEED for valid design data covering the effectiveness of different methods for retaining bearings in housings, the bearings being subjected to axial thrust loads, a program of tests and study conducted at Northrop Aircraft has yielded much pertinent engineering information associated with the swaging methods of retaining bearings.

Where space is available for their application, snap-ring and screw-in ring constructions, Fig. 1(A) and (B), offer no serious design and production problems. The dimensional values and the physical properties such as yield, tensile and shear strengths of the materials determine the retaining strength of the construction. The program was limited, therefore, to the investigation of swaging methods that could be used where space is insufficient to install snap-rings and screw-in rings.

Tests were conducted from which data were obtained on bearings retained by press swaging, friction spin swaging, and roll swaging. These data indicate that press swaging and friction spin swaging are unsatisfactory for retaining bearings in any but the more ductile materials such as 24SO aluminum, 75SO aluminum, and steel of 125,000 psi tensile strength or less.

These data also indicated that the roll swage method, when housing grooves and rolling tools are properly proportioned, is reliable and practical for retaining bearings in ductile materials, and in the more brittle and notch sensitive materials.

In exploring the possibilities of press swaging, housings of 165,000 psi tensile strength steel, 75ST aluminum, FS-1h magnesium wrought alloy, and an aluminum casting alloy were machined with a groove as shown in Fig. 2(A). With the simple press type tools shown in Fig. 2(B) and a Universal testing machine, 1.750 in. diameter bearings were swaged into the several housings.

Press swaging the ring of pre-grooved material around the bearing was successfully performed with housings of ductile steel and the annealed aluminum alloys. In housings of 75ST

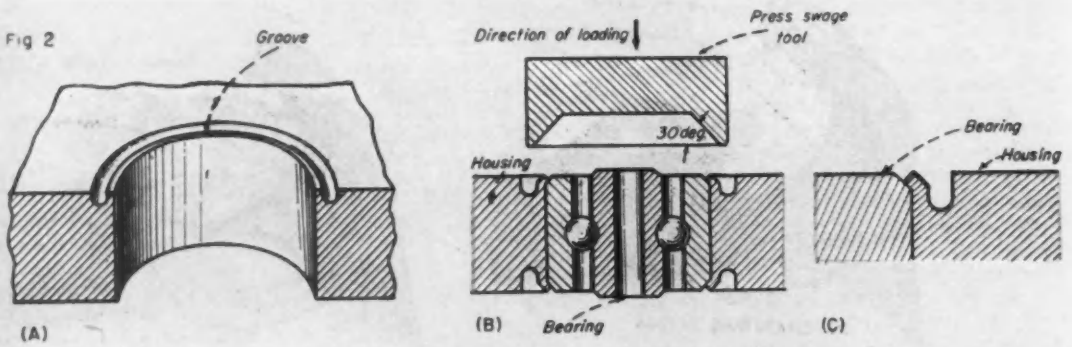


Fig. 2—Press swage process for retaining bearings in housings. (A) Machined groove in housing. (B) Press swage tool, housing and bearing. (C) Swaged housing ring and bearing. Push-out loads were satisfactory.

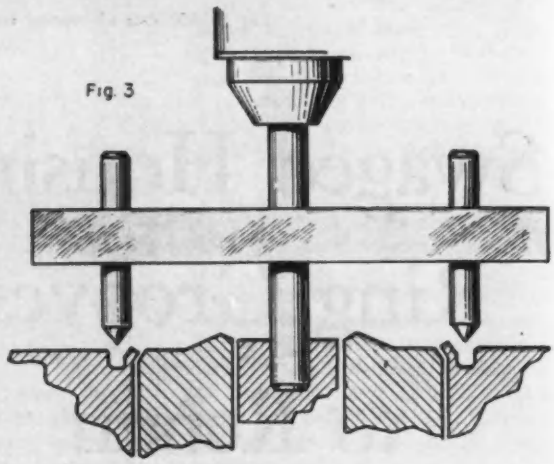
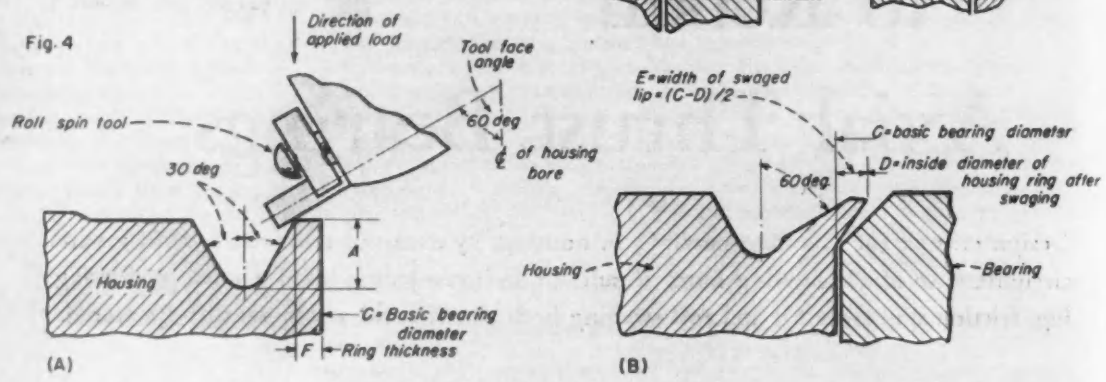


Fig. 3—Set-up for friction spin swaging using a drill press. Hard housing materials cut grooves in tool.

Fig. 4—(A) Housing and tool relationship prior to roll swaging. (B) Housing ring and bearing after swaging.

Fig. 5—Standardized dimensions and tolerances adopted for retaining bearings in housings by roll swaging. Table I relates data with specific metals.



aluminum, FS-1h magnesium, and the casting alloys, however, the ductility was not sufficient to withstand the bending stresses induced by press swaging at the root of the groove. The rings consequently cracked in these areas.

The push-out load results obtained with press swaging were high for the ductile materials, thus indicating that swage retention would be applicable for most retained bearings if a method satisfactory for all commonly used alloys could be developed.

Since only a small area of the groove is under pressure of the tool during spin swaging, it was surmised that in spin swaging the bending stresses in the groove area beneath the tool would be less than those when the whole ring is pressed swaged.

Exploratory tests of spin swaging, therefore, were next made. Using similar materials, bearings, and groove design as those used in the press swaging tests, housing rings were swaged over bearings with a friction type tool, Fig. 3, mounted in a drill press.

Spin swaging was not satisfactory when tried using a friction tool. Instead of swaging the housing material over the bearing, the tool face, of hardness Rockwell C-61, was grooved by the stronger and harder materials such as 165,000 psi tensile strength steel and 75S-T6 aluminum. On softer materials such as 75SO aluminum, FS-1 wrought magnesium and H-HT magnesium castings, spin swaging was accomplished satisfactorily except that excessive galling occurred on the face of the housing ring.

From the spin swaging tests, it was concluded that:

1. A roller type swaging tool would be necessary to produce satisfactory parts.

2. The tool face angle necessary for optimum swaging conditions must be determined.

3. The limits must be determined for depth and width of ring groove, for angle of groove taper from top to root, and for thickness of ring at root of groove to achieve satisfactory resistance to axial loads.

Table I—Design Data for Roll Swaging Process of Retaining Bearings

Tolerances on dimension *A* for all materials are +0.005 and −0.000
For permissible reswaging, tolerances on dimension *E* for all materials are +0.001 and −0.001
For permanently installed bearings, tolerances on dimension *E* for all materials are +0.0025 and −0.000
A tool face angle as shown in Fig. 5 is used with these design data

Material	Groove Depth, *A*	Chamfer Depth, *B*	Reswaging Permissible		Permanently Installed	
			Lip width, *E*	Design Load per in. of housing diameter, lb	Lip width, *E*	Design Load per in. of housing diameter, lb
Aluminum (75S-T6)	0.045	0.060 to 0.035	0.005	690	0.0125	1730
	0.025	0.034 or less	0.0035	660	0.0075	1410
Magnesium (FS-1h)	0.045	0.060 to 0.035	0.005	260	0.0125	650
	0.025	0.034 or less			0.0075	520
Steel*	0.045	0.060 to 0.035	0.005	1020	0.0125	2540
	0.025	0.034 or less	0.005	1270	0.0075	2040
Al Casting (356-T6)	0.045	0.060 to 0.035		260	0.0125	650
	0.025	0.034 or less		Retention not possible	0.0075	520
Mg Casting (H-HT)	0.045	0.060 to 0.035	0.005	350	0.0125	860
	0.025	0.034 or less		Retention not possible	0.0075	630
Steel Casting (SAE 4130)	0.045	0.060 to 0.035	Have not used to date		0.0125	Have not used to date
	0.025	0.034 or less			0.0075	

*SAE 4130 (165,000 to 185,000 psi); SAE 4140 (185,000 to 200,000 psi); SAE 4340 (200,000 to 220,000 psi).

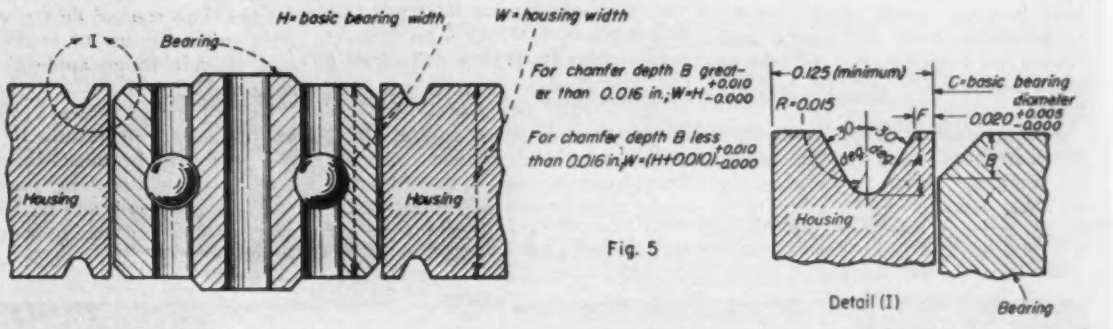


Fig. 5

4. The effect of bearing diameter on the unit push-out load must be investigated.

5. Push-out loads obtained were sufficiently high to allow the use of the swaging method to retain all or nearly all bearings even if misaligned or subjected to vibrational axial loads.

Further tests were then conducted using a roller type tool, Fig. 4, using either a lathe or a mill, to determine the optimum conditions for roll swage retention of bearings. Housing diameters ranged from 0.750 to 3.5 in. All commonly used wrought and cast materials were investigated to determine the design characteristics.

A series of tests were made in which the tool face angle was varied from 45 to 70 deg. In these tests, cracking of the ring as a result of bending stresses occurred in the less ductile materials such as 75ST aluminum and FS-1h magnesium. At 70 deg face angle, the tool clearance was insufficient with some types and diameters of bearings. A tool face angle of 60 deg to the housing bore axis was determined to be the optimum.

The ring groove on some specimens was tapered from top to bottom, on others its sides were parallel. Cracking occurred for the less ductile materials when parallel sides were used. The optimum ring shape was one in which the groove sides tapered 30 deg from top to root, forming a 60 deg included angle.

Using this optimum tool face angle and this optimum ring shape, tests were then made using only 75ST aluminum in which the thickness *F* of ring, the depth *A* of the groove, and the width *E* of the swaged lip, Fig. 4, were varied to determine the optimum dimensional limits.

Since ring thicknesses in the range of 0.015 to 0.040 in. were found to be satisfactory physically and metallurgically, a ring thickness of 0.020 to 0.025 in. was selected as the optimum standard dimension for design.

A maximum groove depth of 0.050 in. was consistently satisfactory metallurgically. An amount of rolling to swage a lip of 0.025 in. wide was satisfactory metallurgically and physi-

cally for the samples tested. Shear type swaged ring defects occurred when the width of the ring lip was increased beyond 0.025 in. To give a safety factor to account for the limited number of tests and variation in materials, a value of 0.015 in. was set for the maximum amount of lip width.

Using the standardized dimensions and tolerances given in Figs. 4 and 5 and Table I, several specimens each of SAE 4130 steel (165,000 psi), SAE 4340 steel (200,000 psi), 75S-T6 aluminum, FS-1h magnesium, SAE 4130 cast steel (165,000 psi), 356-T6 sand cast aluminum, and H-HT sand cast magnesium were rolled swaged over bearings ranging from 0.75 to 3.50 in. dia. The retained bearings were then loaded axially and the failure loads of the swaged rings recorded.

In addition, a series of identical tests were run on 75S-T6 aluminum roll swaged housings to determine the variation in failure loads.

On the basis of these tests, a safe design load for roll swaged bearings was determined to be

$$\text{Design Load} = \text{Failure Load}/1.5$$

It should be noted, however, in designing to the roll swage process that the manufacturer's rated thrust load for any bearing must first be considered and then the design load for the roll swage process. Whichever is the lower load should be used for design.

After evaluating all tests, data were compiled from which the dimensions for design and fabrication as given in Table I and Figs. 4 and 5 were set up as being satisfactory for bearings retained by the roll swaging process. Note that the design loads as given in Table I are pounds per inch of housing diameter. The values given are applicable to any diameter of housing bore.

In making a complete metallurgical examination, roll swaged specimens for all conditions of the tests were examined for cracks, metallurgical defects and microstructure. On the exploratory tests, cracking and shear defects were encountered as previously discussed. On all cracked rings, evidences of a cold forged structure such as deformation bands were few, indicating that little forging and mostly bending had occurred.

Metallurgical examination of cross-sections of roll swaged bearing housing rings that were made to the final standardized dimensions given in Table I show a sound swaged (forged) microstructure free from cracking or other defects.

A typical cross section (35X) of a roll swaged housing ring, 0.050 in. deep, is shown in Fig. 6(A). This micro photograph reveals a satisfactory cold forged structure for permanently installed bearings.

In Fig. 6(B), a typical cross section (50X) is shown of a roll swaged housing after the bearing was pushed out. This housing was machined to a ring depth of 0.025 in. This housing is satisfactory for replacing the bearing and reswaging.

The 250X micrograph of the swaged structure shown in Fig. 6(C), reveals extensive deformation banding. These bands are too fine to be detected in the other lower power micrographs.

In Fig. 6(D) is shown a typical shear defect (35X) that occurred when the housing ring was swaged to a ring lip width greater than 0.025 inch.

Conclusions

The roll swage method of retaining bearings is readily adaptable to production on a vertical or horizontal mill. The set-up requires only one tool and tool holder to cover all diameters of bearings. For each I.D. of bearing, however, a separate locating plug is needed to position the bearing and housing in the work holding fixture.

After three years production experience, this process has been found to be highly satisfactory, with minor exceptions. Manufacturing difficulties, were experienced in obtaining a controlled amount of swaged lip. At present, therefore, all parts incorporating the roll swage method are designed so as to allow replacement of the whole bearing unit rather than the bearing itself.

It is present manufacturing practice to roll the lip over as far as possible by operator feel until excessive resistance is felt. This technique has been found satisfactory for all materials listed in Table I. However, in the initial production of some H-HTA casting parts with roll swaged bearing housings, an excessive number of swaged rings cracked during swaging. As a result, the use of H-HTA castings in roll swage applications has been discontinued.

The roll swage method as discussed in this article for retaining bearings has proved to be satisfactory in the brittle and notch sensitive materials as well as in the ductile and easily swaged materials used for bearing housings.

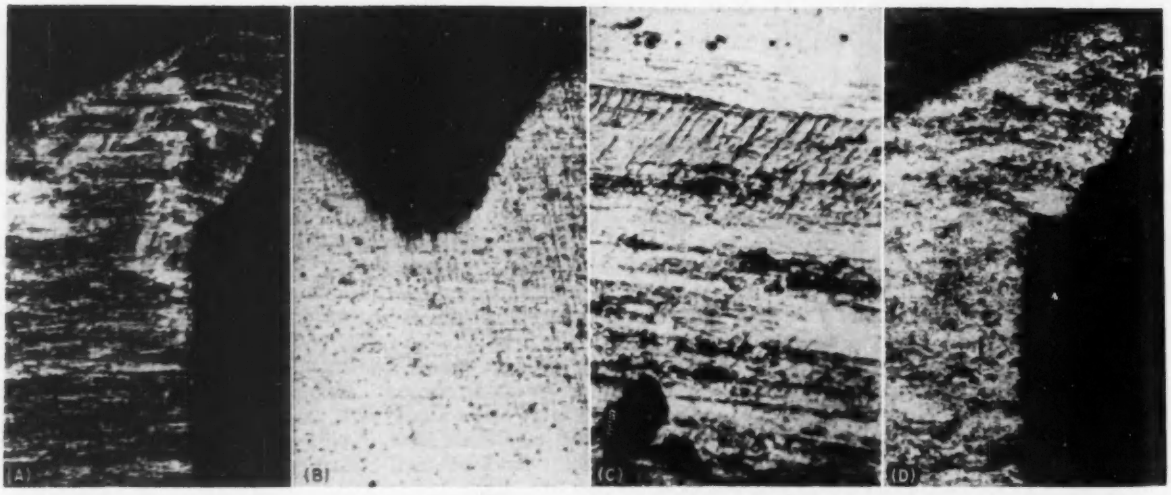


Fig. 6—Metallurgical characteristics of roll swaged sections of housing rings. (A) Typical structure for permanent installation of bearings. (B) Typical structure after bearing push-out, which was found to be satisfactory for reswaging. (C) Deformation banding as a result of cold forging during swaging. (D) Shear defect that occurs with extreme swaging.

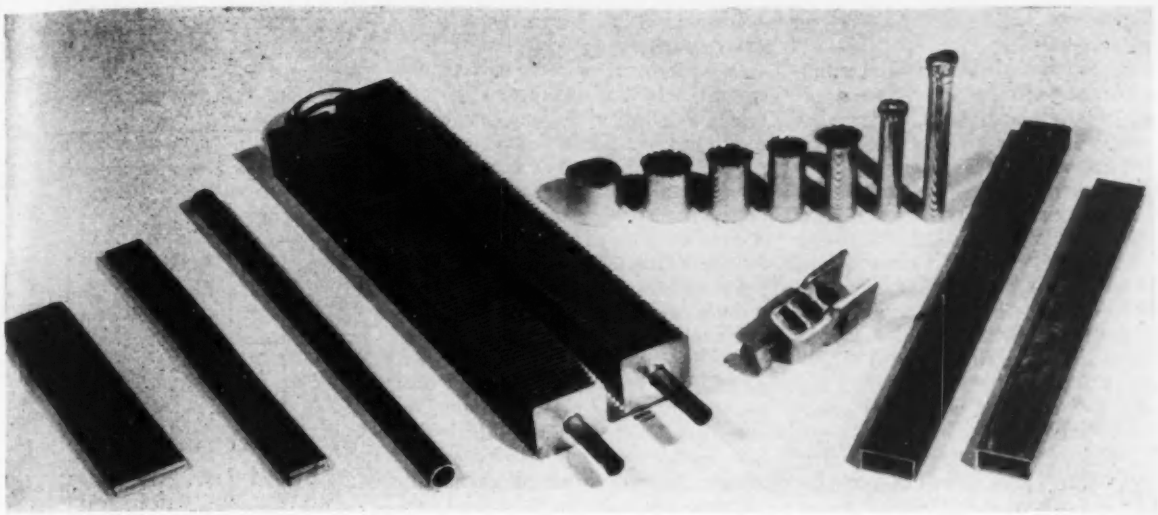


Fig. 1—Products fabricated from copper-clad aluminum include radiator fins, wave guide tubing, and cable connectors, among others.

Composite Metals:

A New Key to Design Flexibility

Metallurgically bonded metal combinations can be used to overcome many of the engineering limitations of single metals and to conserve critical and high cost materials. A large variety of composites are now available.

JEROME OTTMAR
Manager, Engineering and Sales
General Plate Division
Metals & Controls Corporation

THE METALLURGICAL BONDING of practically any combination of malleable metals is now possible through recent progress in the development of new metal bonding techniques. These composite metals provide a new group of engineering metals with (1) combinations of desirable engineering properties many of which are not available in single metals; (2) increased overall strength; (3) decreased material weight; (4) improved fabricating characteristics; (5) fewer critical alloys; (6) lower cost.

Composite metals, sometimes referred to as clad metals, bimetals or trimetals, sandwich metals, and occasionally as laminated metals, consist of two or more single metals inseparably bonded—usually under heat and pressure—to provide a material with each layer of uniform thickness. Some of the composite metals commercially available today include:

(a) Aluminum base composites
(b) Iron and steel base composites
(c) Stainless steel clad-metals
(d) Special spring materials
(e) Brazing metal cladding
(f) Thermostat metals
(g) Rare metal and precious metal clad materials
(h) Lead clad metals

Aluminum Base Materials

Aluminum is ideal for the base or backing metal for composite metals because of its light weight, ductility, high thermal and electrical conductivity, good corrosion resistance, and its availability.

Aluminum with copper clad on one or both sides is one of the most interesting combinations. Until recently it was principally used by the manufacturers of split bolt and washer type connectors for aluminum conductors. Previously the aluminum cabling terminated in conventional copper switch gear; galvanic couples resulting at the junction caused severe corrosion problems. Washers or shims made from the single-clad materials alleviate this problem. The aluminum side contacts the aluminum cabling and the copper side contacts the copper terminal of the switch gear. With the trend toward the use of aluminum for current-carrying applications this copper-clad material is providing the solution to many termination problems.

In the electronics field copper-clad aluminum is a preferred material for component housings or cases, chassis, and inter-chassis frames. It can be readily worked in production and its light weight is particularly important

for aircraft equipment. The copper provides an ideal surface for the soft-soldering operations used in grounding, sealing of component cases, securing of brackets to cases, and similar operations. Also the single or double-clad copper surface provides a base for further finishes or electroplating.

The thermal conductivity and light weight of copper-clad aluminum also make this material advantageous for use in heat transfer assemblies, condensers and similar applications. Other uses include electrical connector blades and parts, emblems and similar products fabricated by coining, bus bars, and stamped circuits for electronic equipment.

Tin-clad and zinc-clad aluminum have only recently been put into production. These materials have the basic characteristics of aluminum and provide a nonporous surface of tin or zinc for use as a soft solder.

Light weight contact components requiring no flexing are fabricated from silver-clad aluminum—the silver surface layer being a preferred contact material. In this instance weight is minimized and the overall material cost is reduced since precious metal is used only at points of contact. One typical application is a small contact or stylus that moves about the silver surface of a large stationary contact fabricated from silver-clad aluminum.

Composite metal tubing is frequently used for rectangular wave guide tubing for electron transmission lines. Aluminum base metal can be specified to keep the weight of the wave guide tubing to a minimum. A fine silver lining with a polished surface provides efficient electron transmission. Silver-lined aluminum tubing can also be supplied with a thin layer of copper clad to the outside of the tube to facilitate soft-soldering operations. An equivalent silver-lined brass tubing is also manufactured.

Type			Condition (Hard = 40% Red.)	Yield Strength, psi, 0.2% offset
Cu	Al	Cu		
10	90	..	Soft	5,700 to 7,100
			Hard	18,500 to 21,400
5	90	5	Soft	5,700 to 7,100
			Hard	19,900 to 22,800
20	80	..	Soft	6,400 to 7,800
			Hard	22,800 to 25,600
10	80	10	Soft	6,400 to 7,800
			Hard	22,800 to 25,600
30	70	..	Soft	7,100 to 8,050
			Hard	24,200 to 27,000
15	70	15	Soft	7,100 to 8,050
			Hard	25,600 to 28,500
Aluminum			Soft	5,000
			Hard	21,000
Copper			Soft	11,000
			Hard	46,000

Ferrous Base Metal Composites

Aluminum-clad steel, combining the surface characteristics of aluminum with the physical and mechanical properties of steel, frequently replaces other materials because of its proven heat-reflective and heat-resistant properties, and its ability to resist corrosion at elevated temperatures.

Heat exchanger tubes, liners and component parts for space heaters, water heaters, and ranges, aircraft fire walls and toaster inner parts are a few typical applications. It is presently being considered as a replacement for copper-alloy shrouds on lamp-base sockets for outdoor fixtures. In this case the aluminum surface resists atmospheric corrosion and the steel backing provides sufficient strength to allow a substantial reduction in the gage of material required.

Aluminum-clad low carbon steel strips are used to replace pure nickel in many electron tubes. This material has proven comparable to pure nickel for many electron tube parts and has also reduced cost. It is more economical than nickel and its lower density gives about 30 percent more parts per pound. Further cost reduction is obtained by the removal of the carbonizing operation required on some nickel parts. The clad material is supplied with a matte finish that provides maximum radiation properties after parts are "blackened" by firing. The radiation coefficient of the "blackened" material is about 85 percent of a black body.

For some electronic tube parts the requirements call for a thin nickel layer on one side of the material. This material is a low carbon steel with a 10 percent cladding of aluminum on one side and 10 percent pure nickel on the other. Another material has a thin nickel layer on both sides.

Clad steel bullet jackets have replaced solid gilding metal (90 percent copper-10 percent zinc alloy) and solid cupro-nickel (80 percent copper-20 percent nickel alloy) jackets making available large tonnages of copper, zinc, and critical nickel for other purposes. For this application, gilding metal is clad to both sides of a steel core. Several steel companies have produced this composite metal for small arms ammunitions. Present clad billets of 2,000-3,000 lb permit high yield of usable material in fabrication. Processes for separating the steel and copper alloy cladding permit salvage of steel and copper from the scrap.

Stainless Clad Metals

Stainless-clad copper combines the high thermal conductivity of copper with the high temperature and corrosion resistance of stainless. The thermal conductivity of solid stainless is one of the poorest of all constructional metals, although the high temperature and corrosion-resistance properties are good. Stainless-clad copper possesses a much higher thermal conductivity than solid stainless and eliminates the formation of hot spots at the point of heat concentration. Tests have shown that a 25/50/25 thickness ratio of double-clad stainless on copper provides an apparent lateral conductivity higher than solid copper. This point is explained by the fact that the stainless cladding is a partial heat insulator. The heat, therefore, is unable to dissipate as rapidly at it does with solid copper. Cooking utensils, ironers, and simliar products are typical applications where stainless-clad copper is desirable for uniform heat transfer. In other applications such as jet engine or gas turbine components, exhaust manifolds, and similar parts, the copper core is desired to increase lateral heat flow and prevent hot spot formations which might cause cracking or buckling.

Stainless-clad aluminum also has high thermal and corrosion resistant properties and its further development shows promise for many applications.

Stainless-clad low carbon steel is a low cost combination and is used in applications requiring the corrosion resistance of stainless steel.

There are some bearing applications

Table I—Properties of Various Grades of Copper-Clad Aluminum

Tensile strength, psi	% Elongation	Vic. hardness 100g load, sheet .020"		Modulus of elasticity, psi	Density gm/cc	Heat conductivity cal/cm/sec/°C.	Coefficient of linear expansion x 10⁻⁶ 0–100 C.	Elec. resistivity ohms/mil ft.	Elec. con- % IACS	Erichsen test, Cu outside sheet 0.020"	Erichsen test Al outside sheet 0.020"
		Al	Cu								
12,800 to 15,600	31–28	33	70	10,400,000	3.33	0.54	23.3	16.2	61–63	6.5	6.3
25,600 to 28,500	7–5	47	105								
12,800 to 15,600	31–28	..	72	10,100,000	3.33	0.54	23.3	16.1	61–63		
25,600 to 28,500	7–5	..	107								
14,200 to 17,100	33–30	33	70	10,800,000	4.0	0.58	22.5	15.7	64–66	6.9	6.7
27,000 to 30,000	7–5	46	105								
14,200 to 17,100	33–30	..	70	10,250,000	4.0	0.58	22.5	15.2	64–66		
27,000 to 30,000	7–5	..	105								
17,100 to 19,900	36–34	33	69	11,500,000	4.5	0.62	21.8	15.1	68–69.5	6.9	6.7
28,500 to 32,800	8–6	47	104								
17,100 to 19,900	36–34	..	70	10,550,000	4.5	0.62	21.8	14.4	68–69.5		
28,500 to 32,800	8–6	..	105								
13,000	35	27		9,800,000					57		
24,000	5	49	..		2.71	0.52	23.8	17.6			6.4
35,000	36	..	52	16,000,000				10.4	100		
55,000	5	..	105		8.93	0.92	16.8			7.5	

in which an aluminum bearing alloy is desirable but its low strength has made it unsatisfactory. A new composite metal consisting of aluminum bearing alloy clad to a steel backing metal provides the required strength and fatigue resistance and yet maintains the aluminum alloy properties on the bearing surface.

Spring Metals

There have been some new developments on composite materials for spring components. One material consists of grade *C* phospher bronze integrally bonded to both sides of a copper core for conductive-spring members. Copper is desirable for its high electrical conductivity but is unsatisfactory as a spring material. Phosphor bronze offers high tensile strength and fatigue resistance, but its conductivity is only 11 percent that of copper. The composite provides a combination of good conductivity and good spring properties.

This new composite metal proves to be of greatest value in applications where it is desirable to increase the conductivity of the spring member and still not increase its cross-sectional area. In turn, for any given conductivity, a reduction in cross-sectional area and savings in material or space are obtained. A 25/50/25 thickness ratio has been predominant to date. Specification of other thickness ratios depends on the balance of conductive and fatigue resistant properties required by the part.

Copper clad to one or both sides of hardenable carbon steel is one of the latest composite metals put into production for spring applications. This material compares to beryllium copper in many respects, but with somewhat lower fatigue resistance. Its primary advantage is lower cost.

The electrical conductivity of copper-clad hardenable steel depends principally on the thickness of the copper-cladding. Ratios of thickness for the copper-double-clad on hardenable steel can be produced to offer higher electrical conductivity than beryllium copper when the same overall thicknesses of materials are compared. Also, the stiffness is higher for copper-clad hardenable steel than for beryllium copper. Typical applications are fuse clips, thin blade or spiral type springs, and clips used for electrical connectors not subjected to frequent arcing. In other applications, such as pen and pencil clips, the thin layer of copper provides a good surface for decorative electroplated finishes. In these instances, the thickness of the copper cladding layer need only be as thin as 5 percent of the overall thickness of the material.

Cladding for Brazing

A rather unique development of interest to production men is the cladding of brazing alloys to other materials. The separate handling of small pieces of brazing alloy is eliminated by fabricating parts from materials that have the brazing alloy pre-clad

to the brazing surface. The brazing alloy and parent metal are bonded and rolled similar to the manufacture of other composite materials. The advantages of having the brazing alloy supplied as an integral part of the material is quite obvious—primarily it eliminates the separate fabrication of small pieces of brazing alloy, and the handling of these pieces during the brazing operation, and decreases the number of surfaces to be cleaned and fluxed. It also insures uniform wetting of the surfaces to be joined. Button type electrical contacts are one example of fabricated parts which can be produced from materials with a thin backing layer of brazing alloy.

Another example is a composite consisting of a ductile shim material with silver brazing alloy clad on both sides. This material is widely used for sandwich brazing carbide tips to cutting tools. Previously, the shim material and two pieces of brazing alloy were cut and handled separately. Now, only one piece instead of three has to be cut and handled throughout the brazing operation. The use of this material results in a reduction in the number of metal surfaces to be cleaned and fluxed and actually insures a better bond.

Rare and Precious Metal Cladding

Zirconium, titanium, tantalum, and other similar rare metals are characterized by excellent corrosion resistance, a high melting point, light weight, and other properties which make them preferred for specific applications. Their use has been limited, however, because of their high cost and the difficulty of joining them. A composite metal, consisting of the rare metal bonded to a common base metal, provides a material that preserves the surface qualities of the rare metal, lowers the overall material cost, and simplifies the joining problem. Titanium-clad steel and zirconium-clad nickel are two typical combinations that have been successfully bonded and offer possibilities for engineering and product applications requiring the specific properties of these rare metals.

Platinum, gold, silver, and their alloys clad to less expensive and stronger base metals have been used by the art and jewelry industries for many years. These materials are finding increasing use in industry for crucibles, electrical contact applications and similar uses.

Today a large percentage of electrical contacts are fabricated from composite materials. Considerable savings in cost through precious metal conservation are obtained; the steel, monel and other backing materials also provide desirable properties. For instance, a button type contact with a steel or monel backing facilitates projection welding of the contact to its supporting member.

In many other engineering applications requiring the use of precious metals, it is desirable to keep the precious metal content to a minimum and composite metals are consequently required.

Cost reduction may be the principal goal in the selection of a specific thickness ratio of precious metal to base metal, although in many cases the backing material provides functional properties such as spring characteristics, rigidity, magnetism, and thermal and electrical conductivity.

Techniques of manufacture make it possible to supply base materials with a precious metal (or other metal) stripe positioned at practically any location. The stripe can be positioned as an in-lay, edge-lay, or thru-lay. For electrical contact applications, a material is used where the stripe of preferred metal is bonded to the top surface of the base to form a rib-like strip that is raised above the base metal surface. Although striped composite metals have been used for diverse applications, their principal use has been for electrical contact members where the backing base metal offers the characteristics required of the supporting member and the precious metal strip provides a non-corrosive high-conductive metal at the point of electrical contact.

Base metal wire with a silver or gold layer on the outside has been produced and marketed for several years for the jewelry trade.

Thermostat Metals

Thermostat metals, one of the older types of composite materials, consists of two or more metals or alloys with differing rates of thermal expansion. Nickel and chromium alloy steels, manganese base alloys, and copper alloy metals are used in various combinations to provide composite metals characterized by a low expansion side and a high expansion side. The resulting thermostat composite provides a bending action when subjected to a change in temperature. The extent of this action is predetermined by appropriate selection of the mating metals. (See PRODUCT ENGINEERING, 1950).

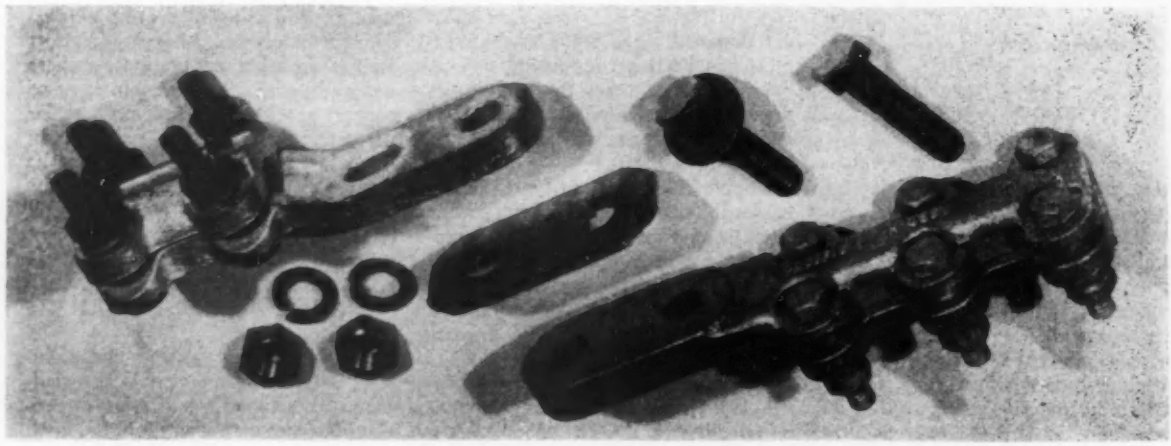


Fig. 2—Transmission line connector sections, with aluminum on one side and copper on the other, are separated by a copper-clad aluminum washers or shim to prevent galvanic corrosion. The aluminum cabling previously terminated in conventional copper switch gear. Galvanic couples at the junction caused severe corrosion problems.

Lead-Clad Metals

Lead-clad steel and lead-clad copper are two recently manufactured composite metals. Lead-clad steel combines lead's immunity to certain chemicals with steel's strength and is a very desirable material for the handling of sulphuric acid. Lead-clad copper combines lead's acid resistance and copper's high electrical and thermal conductivity. This latter material is useful for applications requiring the heating and cooling of sulphuric acid, or to provide improved discharge current for anodes replacing solid lead anodes. Both of these composite metals can be easily worked and fabricated.

The lead layer provides a high density for shielding purposes. This is beneficial in nuclear industries to prevent the escape of harmful radiation.

It is also possible to obtain materials with a single or double clad layer of lead-bearing soft solders. The advantages of fabricating parts from materials with a soft-solder cladding layer would be analogous to the advantages of brazing alloy-clad metals.

Manufacturing and Fabrication Techniques

Two methods of bonding the components of composite metals are generally used—liquid or semi-liquid and solid phase bonding. In the former method, a thin sheet of high temperature brazing alloy is interposed between the metals to be bonded. After brazing, the bonded ingot is put through a series of cold rolling and annealing operations to obtain the desired gage and temper. This method is frequently used to bond precious metals to base metals.

In the solid phase method of bonding the parent metals are bonded directly by application of pressure at an elevated temperature. In many instances the metals are hot rolled to bond them or to insure their final bonding and to simultaneously reduce the composite metal thickness. Final cold rolling reduces the gage and further improves the bond.

The procedures for fabricating composite metals vary depending on the metal combinations and each case should receive individual consideration. Usually, the manufacturer of the composite metal has information available on the techniques of fabrication or the ability of the materials to meet certain fabricating specifications. In many instances, experimental work is required, particularly on some of the newer types.

Blanking and forming, spinning, drawing, and other operations can usually be performed. When considering each part and its related metal, it is usually safe to use the physical properties of the less ductile metal layer as a guide.

Composite metals can be welded in most instances although care should be taken to prevent the preferred metal surface from fusing with the core or backing metal resulting in an objectionable alloy at the surface. When a welding electrode is used on the clad side of the welding seam, the electrode should be richer in the special elements than the cladding layer material. When this is impossible, a series of small beads deposited in the welding groove will keep the dilution to a minimum.

For material subjected to deep-drawing or other forming operations or severe stresses it is important to specify a cladding layer sufficiently thick to prevent its fracture during the stressing. This fracture is usually encountered when drawing or bending thin gage materials where the cladding layer is only a small percentage of the overall material thickness and particularly if the thin layer is the harder of the two bonded metals. This fracture of the cladding metal is in no way a fault of the bonding operation or an indication of an inferior bond between the metal layers. It is caused by stretching the thin cladding layer beyond a point that could be endured by a single metal of equivalent properties and thickness.

Many of the metal combinations discussed here have provided to meet special applications and many other metal combinations will be manufactured and marketed as engineering demands them. A few additional combinations that have been produced are molybdenum-clad Cupro nickel, calcium-clad nickel, platinum-clad stainless, copper-clad magnesium, copper-clad nickel, and nickel-clad copper.

With all of the metal combinations now possible in sheet, tubing and wire forms a study should be made of present metal applications as well as future product designs to determine if a composite metal will reduce material or fabricating cost, provide a combination of engineering properties otherwise unavailable, conserve a critical metal, and/or improve the characteristics of the product.

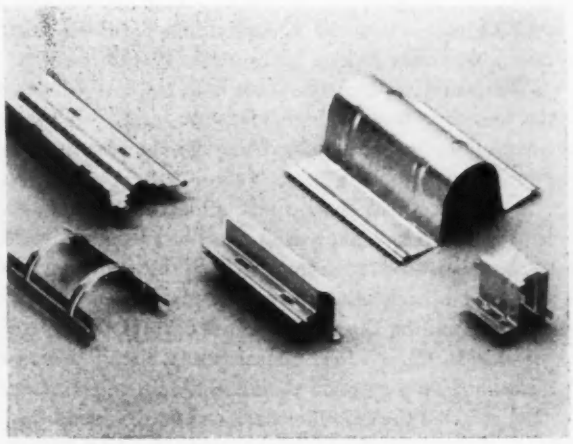


Fig. 3—Electron tube parts which are fabricated from aluminum clad steel, nickel clad steel, and steel with aluminum on one side and nickel on the other conserve critical metals.

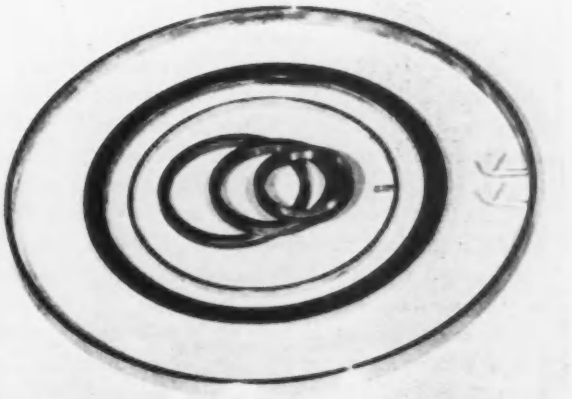
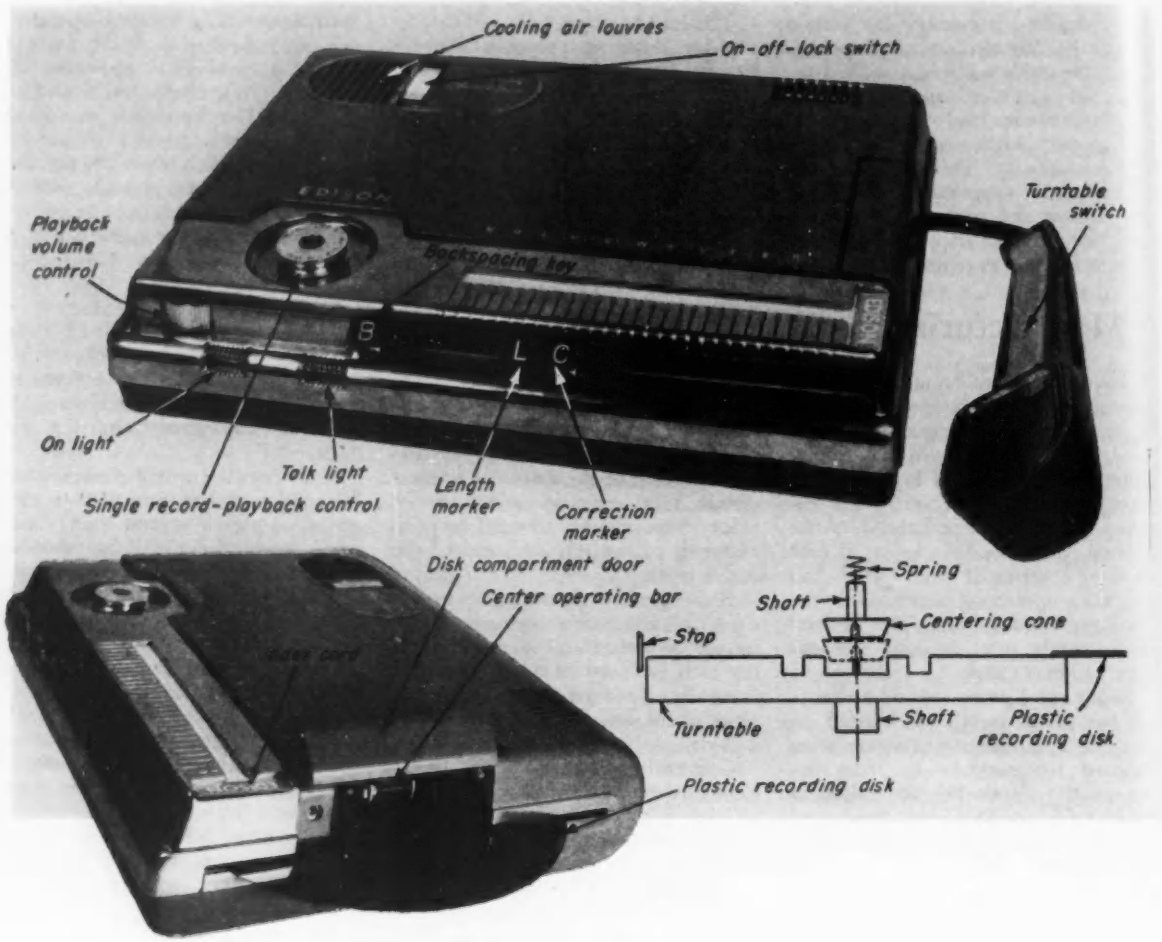


Fig. 4—Collector rings are formed or blanked from silver-clad copper or brass to provide a non-corrosive, conductive surface with good strength, high electrical conductivity and low cost.



Compact Voicewriter Designed

Compact packaging of parts and components enables Thomas A. Edison Incorporated, West Orange, N. J., to produce the new V. P. Edison Voicewriter that is small enough to fit into a standard briefcase or letter case, uses standard size components, and has all the operating features of the standard Voicewriter *(Product Engineering,* May 1949, p. 93). Like its larger counterpart, the "Veep" records by embossing 7 in. plastic disks; but because of the reduction in size, it was necessary to redesign some of the mechanisms to supply these features in the limited space.

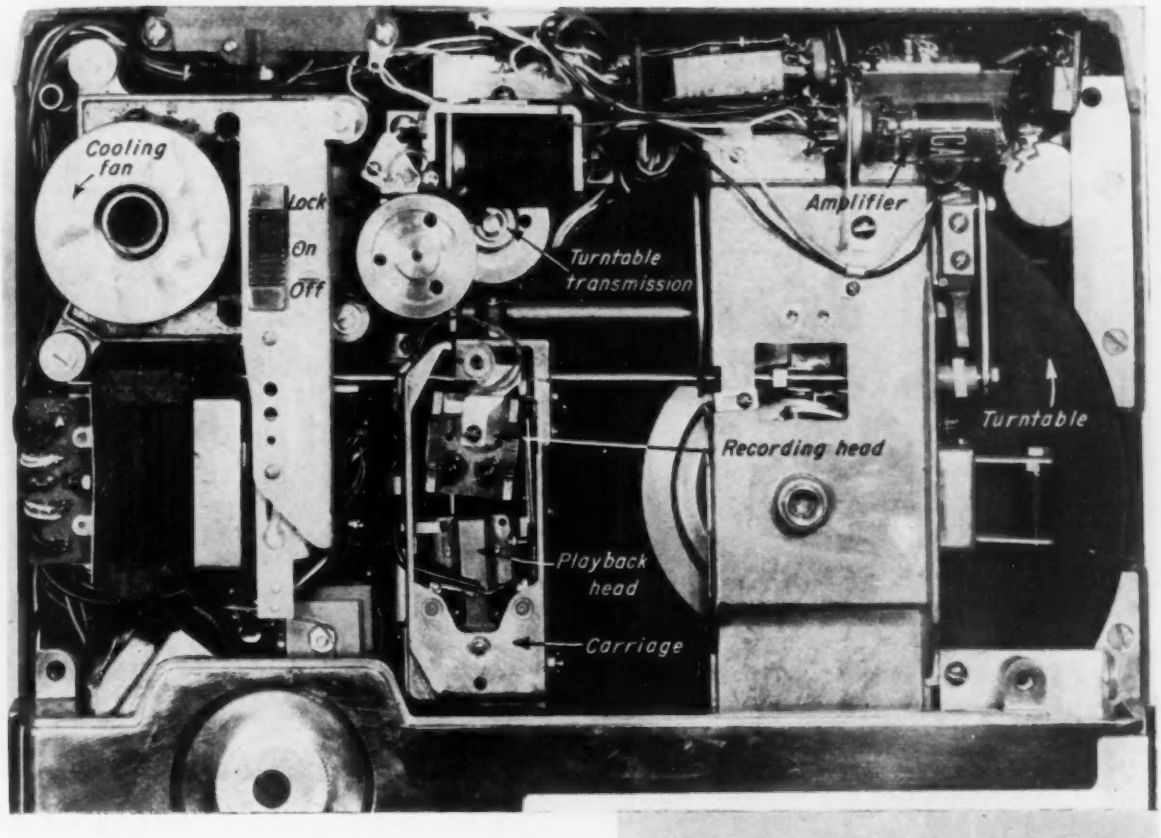
Major innovations include simplified controls; simplified friction drive for the turntable; a new indexing mechanism; and rearrangement, size reduction and simplification of components.

The controls of a conventional dictating machine have been combined into three switches in the "Veep": the on-off-carry switch, the control knob, and the microphone turntable switch.

When the on-off-carry switch is in the carry position, the recording and playback heads are locked against the cover of the machine so that they will not be damaged by movement.

A single control knob controls record, playback, and recall. When the knob is in its normal position, the machine is set for recording and both the recording head and the playback head are on the plastic disk with the playback trailing the record head by a preset number of grooves. In this position the amplifier circuit is set for recording. To play back, the knob is raised. This movement switches the amplifier circuit to playback and raises the recording head from the plastic disk.

If the knob is rotated when in the record position, the machine will "recall" the last few grooves of dictated



FLAT SHAPE is made possible by compact arrangement of components (above). Cooling fan is turbine-type blower that sucks in air and blows it over amplifier and turntable. Playback head trails recording head by about four grooves so that machine can recall last sentence without switching to complete playback.

for Portability

material and play them back. Since both heads are on the disk in this position of the knob, the recording head continues to emboss unmodulated groove. When the knob is returned to its original position, the machine starts recording where it stopped prior to recall. A ratchet mechanism under the knob prevents turning in the wrong direction.

With the control knob it is possible to scan any portion of the record during playback, but it is impossible to scan when in the record position.

Despite space limitations, the band of impressions of on the disk is magnified almost four times on the index card to give the transcriptionist accuracy in locating length and correction marks.

The Veep, designed by Edison engineers, was styled by industrial designer Carl Otto, who used color and curved lines to obtain an attractive appearance.

DISK CENTERING DEVICE (left). Voicewriter records by embossing 7-in. plastic disks that are automatically centered and clamped. With disk compartment door open, disk is inserted until it hits a curved stop. As the door is closed, it cams down an operating bar which forces a cone down through the hole in the disk and automatically centers it. Cone is freely mounted on its shaft so that it rotates with the turntable when it is locked down. Closing door also closes circuit that illuminates talk light to indicate machine is ready to record. However, this circuit will not close unless there is a recording disk in place.

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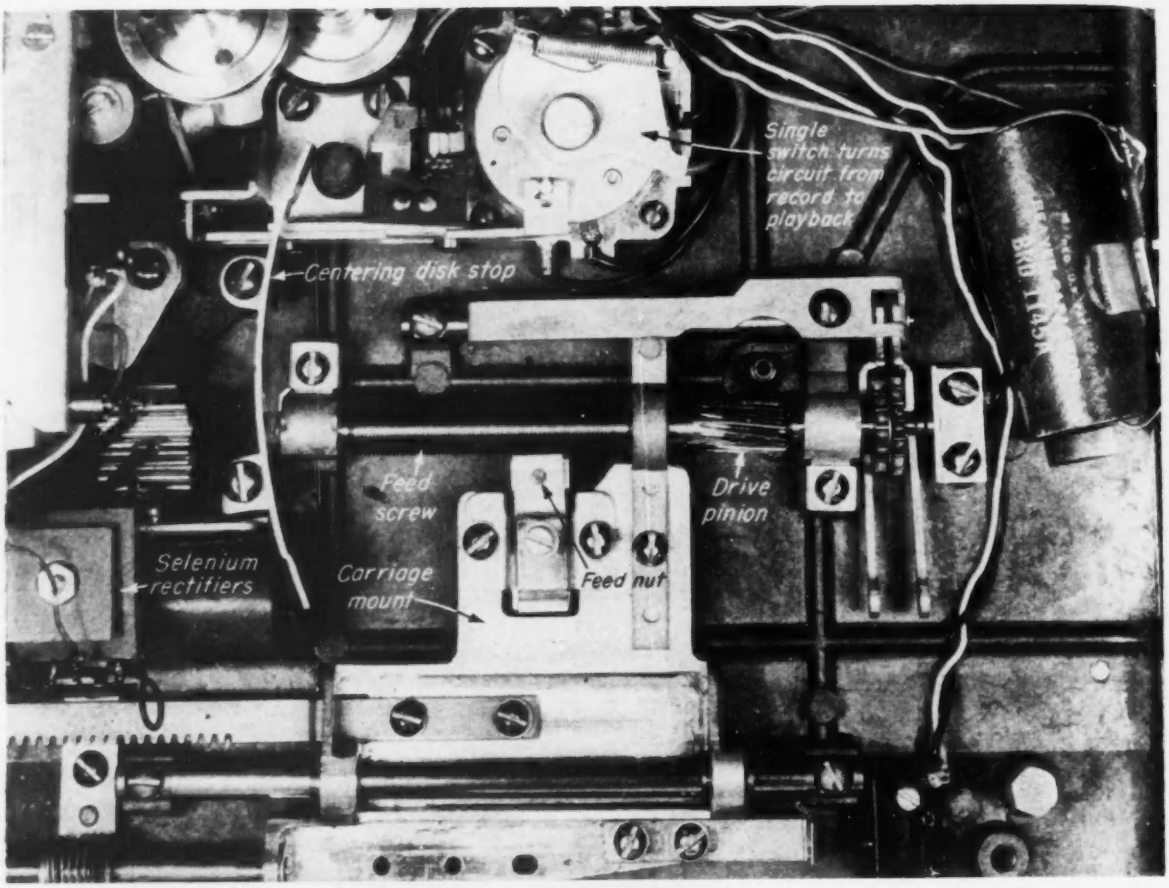
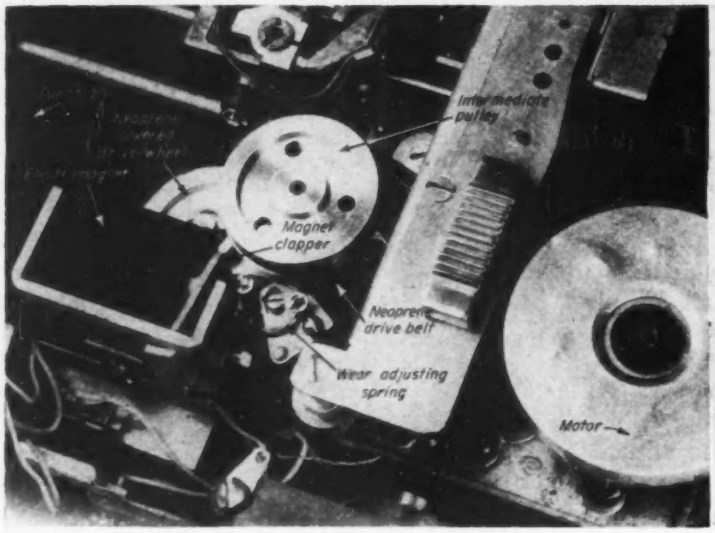
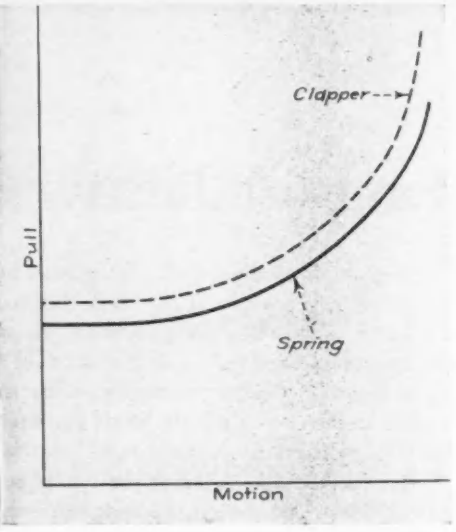
Voicewriter (continued)

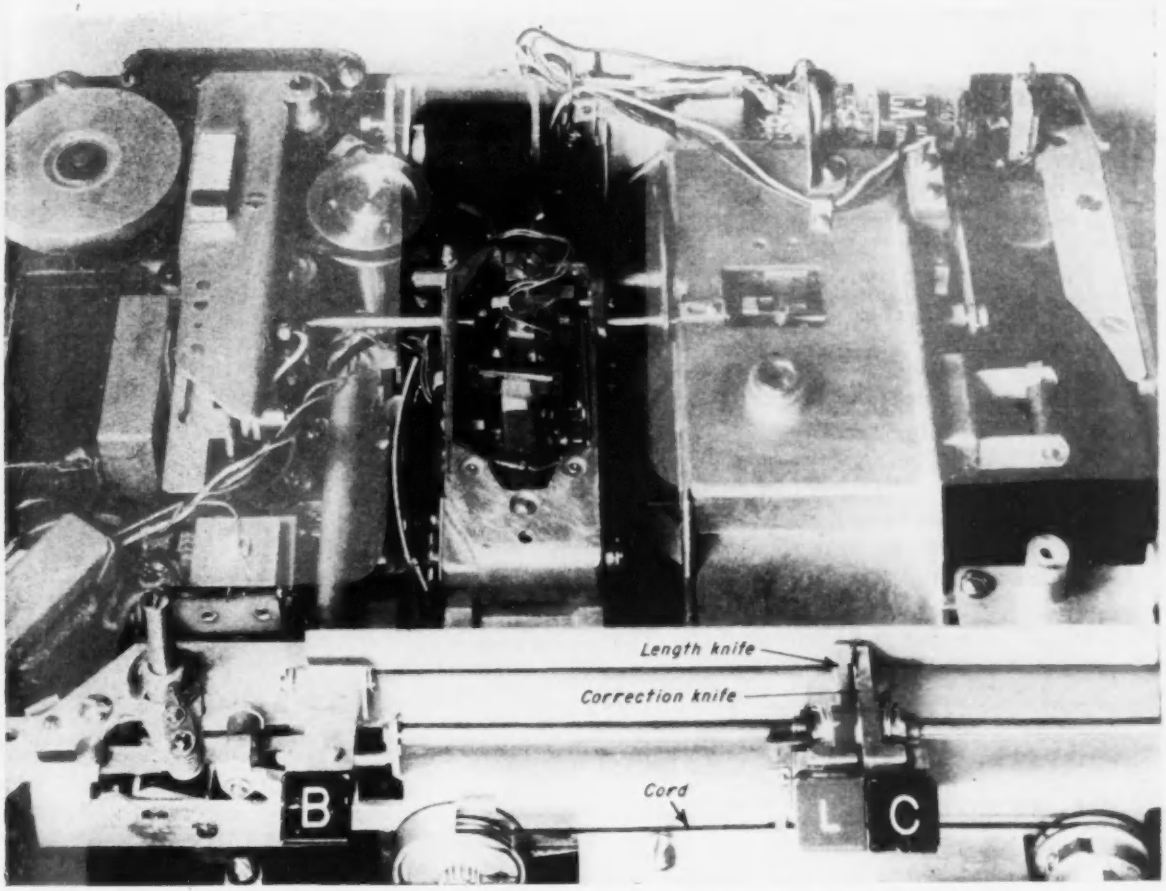


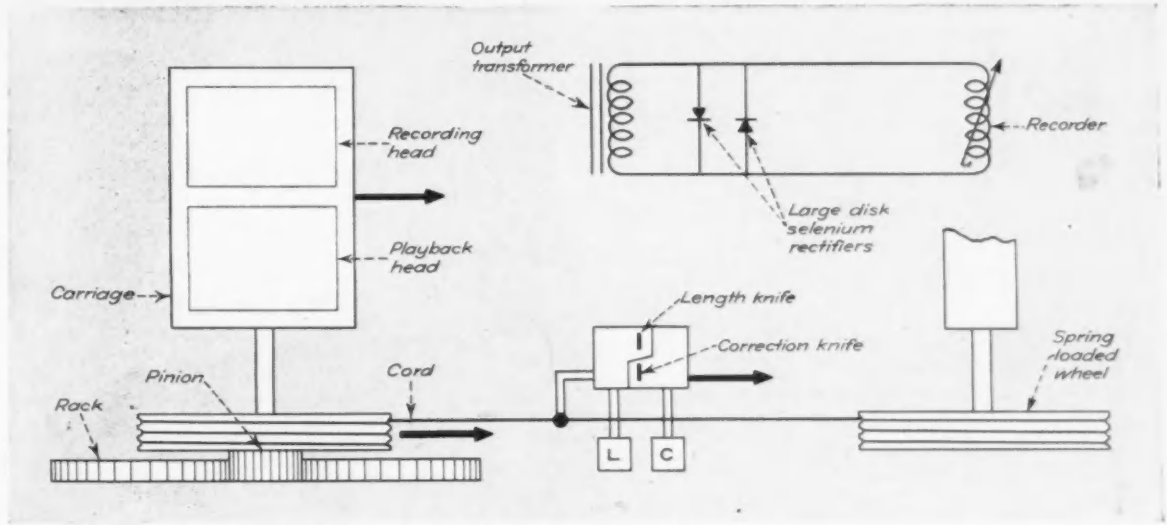




CARRIAGE MOVEMENT (above). Drive pinion meshes with gear mounted on the turntable shaft. As turntable rotates, pinion drives feed screw, and feed nut transforms the rotary motion into transverse motion. This moves the carriage mount that carries the heads across the disk.

TURNTABLE DRIVE is a friction drive (lower left). 1.5 in. oz. torque motor rotates at 2650 rpm continuously when machine is turned on. Rotation is transmitted by a neoprene belt to the intermediate pulley and shaft. When turntable switch on microphone is depressed, the electromagnet is activated, pulling clapper into a position where it actuates a linkage that forces the neoprene-covered drive wheel against the turntable and a rotating pinion on the intermediate shaft. Bow-shaped spring has a pull curve (lower right) which closely follows that of the clapper so that it can compensate for wear of the drive wheel. The spring acts as a solid link for most of the clapper movement.

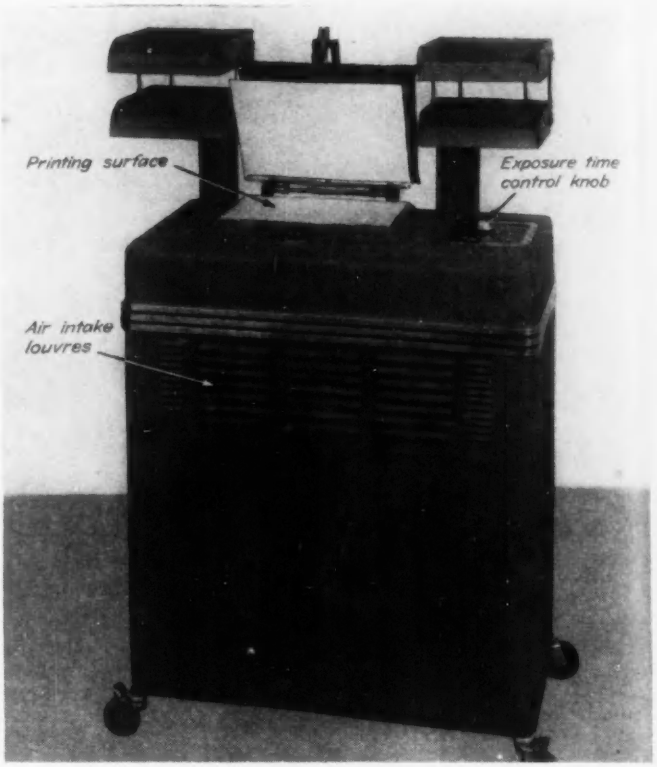




INDEXING MECHANISM operates from below index card. As carriage is moved across disk, it carries left hand wheel of indexing mechanism which revolves on a gear rack. The right hand spring-loaded wheel maintains tension on the cord by winding it up so that the block carrying the knives is moved in relationship to the carriage. Index head moves four times as far as recording head and this ratio is determined by the diameter of the left hand wheel and the size of the gear rack.

SELENIUM RECTIFIERS are used as variable resistors to limit recording volume. When input volume increases past a certain limit because dictator is shouting into microphone, resistance of rectifiers decreases so that output signal is not changed. As a result, transcriptionist hears a constant level of dictation. Purpose of this arrangement is to permit dictation in locations where there is considerable background noise. The dictator can speak loud enough to drown out this noise without impairing the quality of the recording.

Duplicator Reproduces With Heat



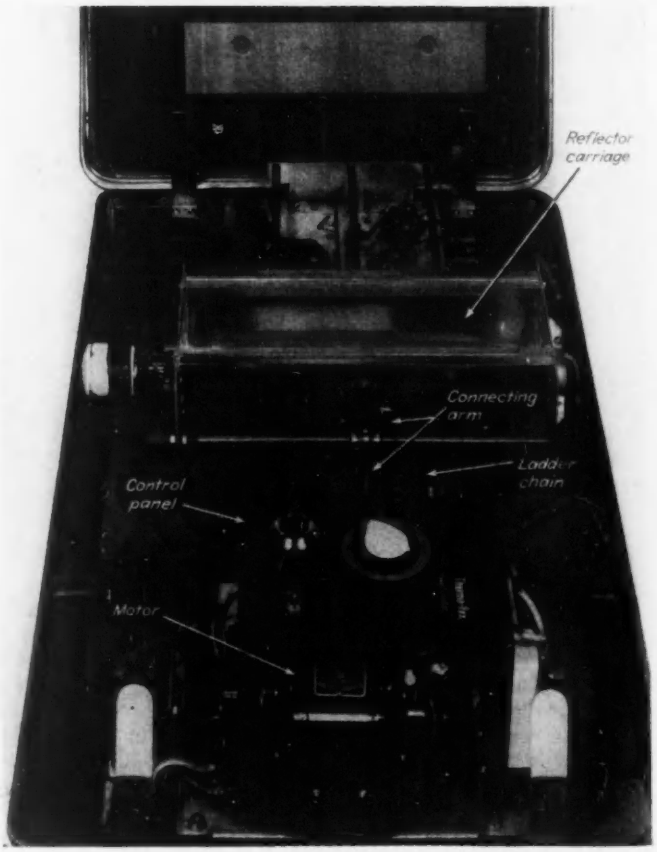
The Thermo-Fax duplicator developed by the Minnesota Mining and Manufacturing Company, St. Paul, Minn., uses infra-red radiation to copy opaque, translucent or transparent originals printed on one side or both. An infra-red light source sends rays to the black and white original so the black type absorbs the energy and converts it into a heat pattern that acts on the Thermo-Fax sheets to reproduce the original. The Thermo-Fax paper is transparent and unaffected by infra-red light.

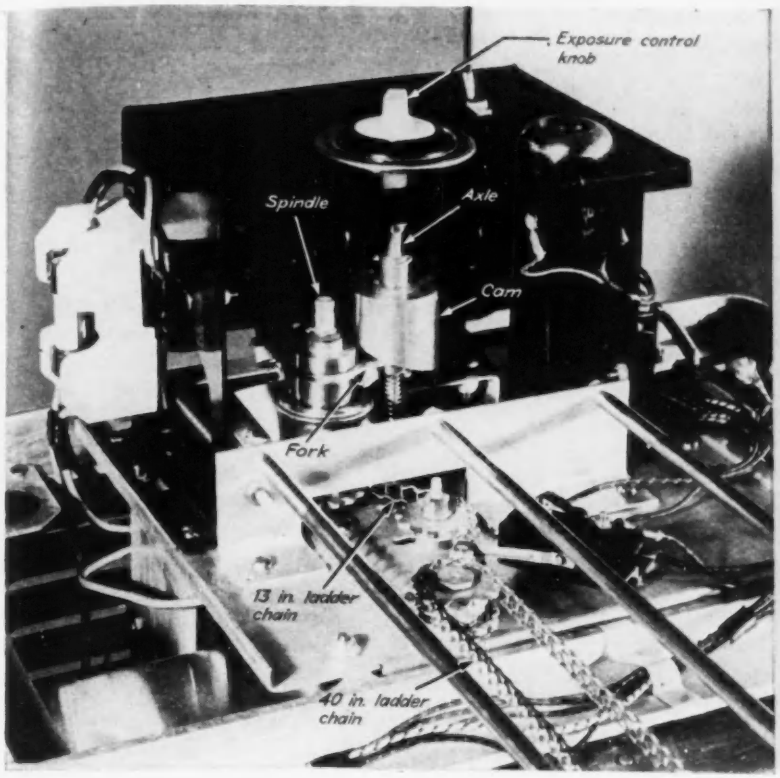
Exposures are made by traversing the lamp across the printing area with a specially designed mechanism that permits two-direction traversing (to make two exposures) on a one-way drive and automatically shuts off the machine at the end of the traverse.

Time of exposure ranges from five to twelve seconds and is determined by the speed of traverse which is regulated by the position of a neoprene hub on a rotating cone. An automatic time delay mechanism is built in to give the lamp time to warm up before the traversing starts. In case the automatic shutoff fails to operate, a circuit breaker trips the machine after the 12-second maximum exposure to prevent burning and damaging the machine or copy.

Power in the drive mechanism is supplied by a 1/150 hp shaded pole motor, operating on 110 volts a-c. A gear reduction box brings the 1600 rpm of the motor down to 89 rpm of the drive shaft which terminates in a grooved 30 degree cone.

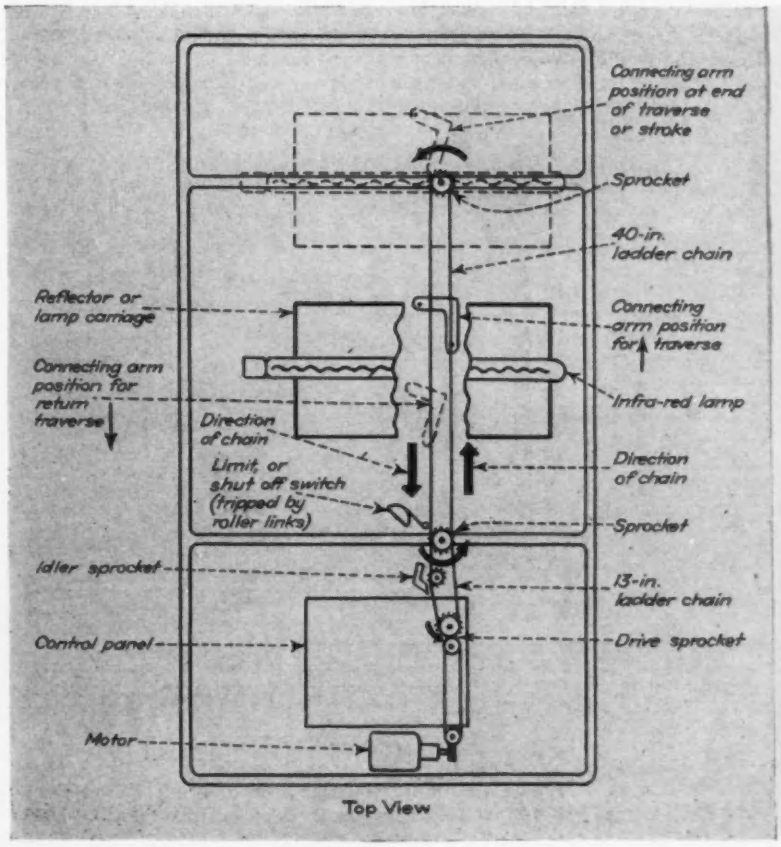
Infra-red radiation is supplied by a 16-in., filament type, lamp with a 12-in. active filament that covers the 8½ by 14 in. printing area. Anodized aluminum elliptical reflector focuses the rays in a ¼ in. wide line. The lamp filament is at one focus of the ellipse and the printing surface is at the other. A centrifugal blower directed at the printing glass aids heat dissipation.





TOP SECTION of duplicator (left) is aluminum casting to provide good heat dissipation. Centrifugal blower directs cooling air to the center of the printing glass and balances the heat loss at the edges of the glass. Louvres in the front and back of the cabinet provide air intake while louvres in the cabinet ends provide exhaust.

EXPOSURE TIME is determined by the time in traverse, and is preset by the operator with pointer knob on the control panel. Turning the knob rotates a cam which raises and lowers a spring-loaded sliding fork. The fork engages a groove in a sliding hub keyed to a spindle that rotates freely on a stud shaft. A neoprene tire on the hub provides a friction drive and is driven by a rotating cone.



ONE-WAY DRIVE (cut left, schematic right). provides traverse in both directions. An "L" shaped connecting arm links the lamp carriage to an endless ladder chain running the length of the machine. When the chain end of the connecting arm goes around the two sprockets, the carriage is stationary and the machine is shut off. Traversing in one direction, the connecting arm pulls the lamp carriage; in the other direction it pushes. This permits making an exposure for each traverse without resetting.

TWO ROLLER LINKS located exactly opposite each other in the 40-in. ladder chain trip the limit or shut-off switch at the end of an exposure to turn off the heat lamp automatically. In addition one of these links serves to pivot the connecting arm to the chain.

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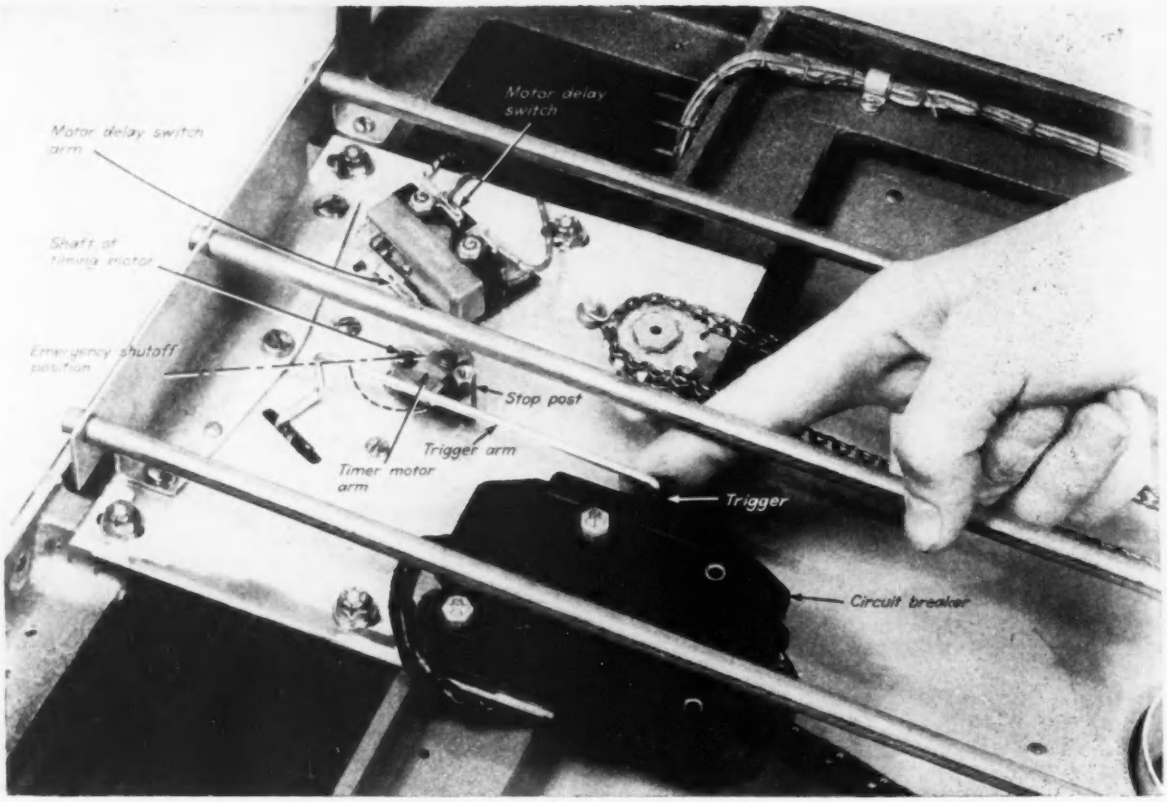
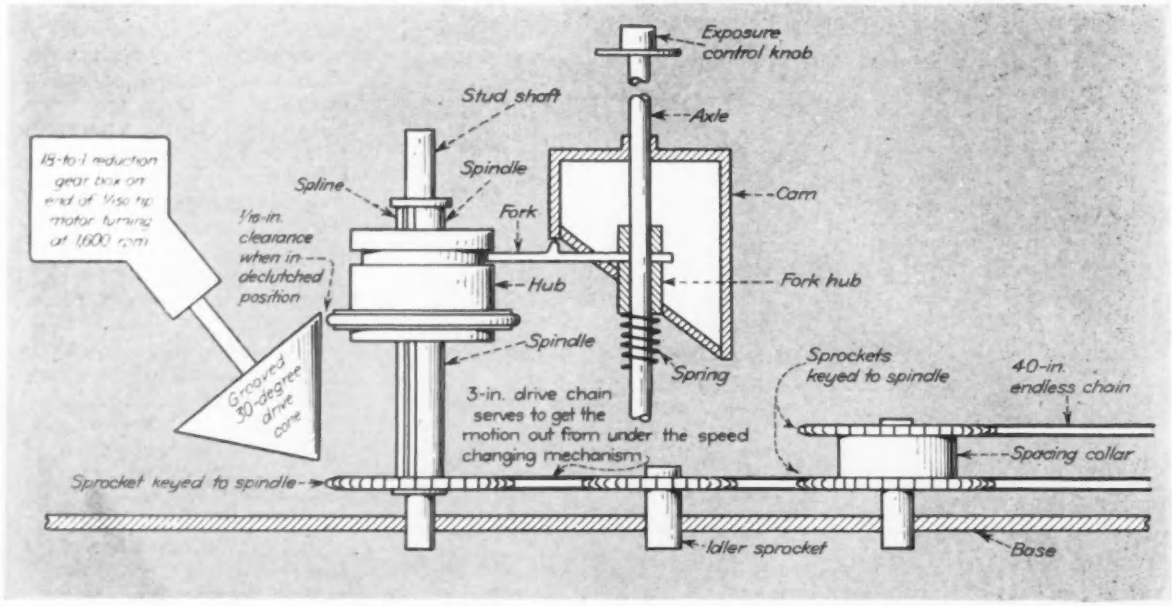
Infra-Red Duplicator (continued)



SYNCHRONOUS TIMING MOTOR provides time delay to permit lamp to come up to temperature before traverse begins. When the start button is pushed the timing motor starts and rotates the timer motor arm away from the stop post. This permits an arm on the motor delay switch to break contact and start the drive motor. If mechanism does not automatically shut off at end of 12 second maximum, timer motor arm rotates until it hits the trigger arm which trips circuit breaker within two seconds after maximum exposure preventing damage to copy.



ROTATING GROOVED DRIVE CONE is driven at 89 rpm through an 18-1 reduction gear box. At highest point (large end of cone) neoprene tire rotates at 89 rpm; at lowest point of travel (near apex of cone) tire rotates at 30 rpm for longest exposure. Motor pivots $\frac{1}{16}$ in. to engage or disengage cone from tire.

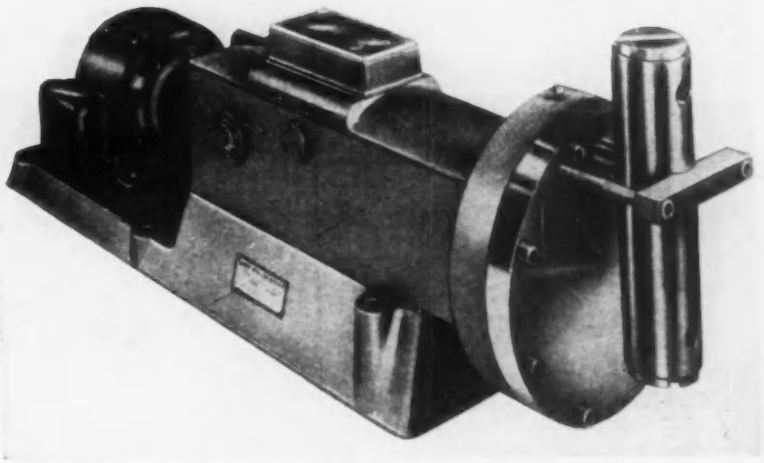
Combination Piston-Diaphragm Pump

In the "Pulsafeeder" built by the Lapp Insulator Co., Inc., Le Roy, N. Y., pumping is performed by the combined action of a piston and a hydraulically balanced diaphragm. The piston reciprocates in an accurately sized cylinder to deliver an exact volume of oil that moves the diaphragm back and forth. Displacement of the diaphragm does the actual pumping of the fluid.

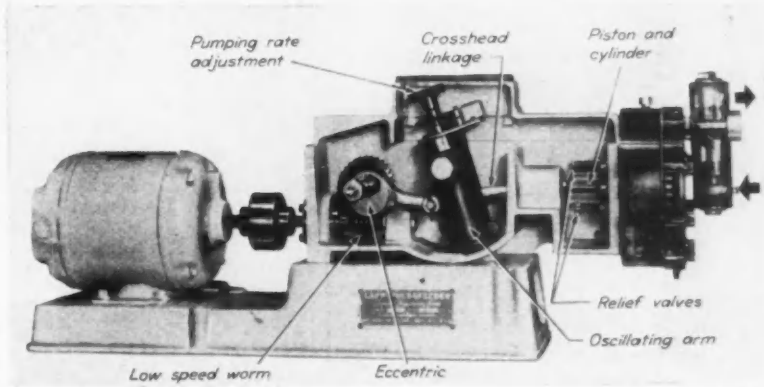
Because of its method of operation, the Pulsafeeder provides controlled volume metering. The amount of fluid pumped depends on the stroke of the piston which determines the amount of diaphragm movement.

The diaphragm support plates restrict diaphragm movement and contain the hydraulic oil and product pumped. Support plate on the hydraulic oil side is the pump head, and the plate on the product side is the reagent head. Each plate has identical concavity to prevent diaphragm deflection beyond the endurance limit of the material. During normal low magnitude deflection, the diaphragm moves freely.

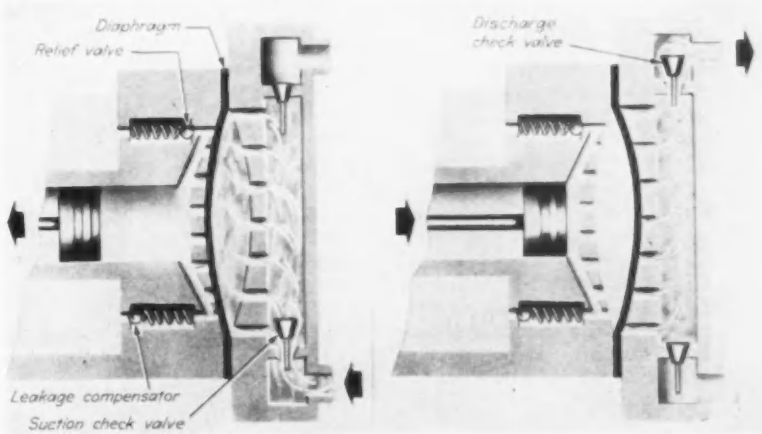
Since the piston handles only oil and the diaphragm isolates the liquid being pumped, Pulsafeeder requires no stuffing box. Leakage of oil past the piston cups is replaced by a vacuum compensator valve; excess pressure is drawn off by a spring loaded relief valve. Both are built into the hydraulic system.



COMBINATION piston-diaphragm pump delivers controlled amounts of chemical fluids. Available in four different models, capacities range from 1.6 gph at 1500 psig to 339 gph at 100 psig.



LENGTH of piston stroke establishes pumping rate that is adjustable from 0 to 100 per cent capacity by turning knurled handwheel, crosshead linkage is positioned with oscillating arm. Eccentric mounted on low speed worm gear converts rotary motion to linear.



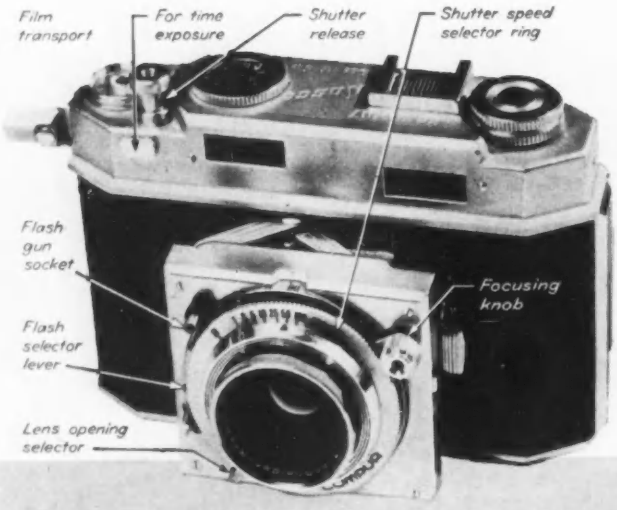
SUCTION STROKE. Piston hydraulically displaces diaphragm to draw fixed amount of liquid through suction check valve. Displacement depends on length of piston stroke.

DISCHARGE STROKE. Return of piston pumps oil into diaphragm area and diaphragm moves liquid through discharge check valve.

Combined Camera Mechanisms Speed Picture Taking

In the new Karomat camera, Ansco has combined operating mechanisms and simplified controls so that the photographer requires less time to take a picture. The film transport mechanism, composed of a precision gear train and operated by one lever, moves the film forward, counts exposures, and cocks the shutter fast enough to permit sequence photography. Focusing is done with a combination split-image rangefinder and viewfinder, and the focusing knob operates both the picture taking lens and the rangefinder. One Kinematic mechanism permits the synchronization of electronic flash or type S and M flash bulbs at all shutter speeds by the movement of the flash selection lever. The flash mechanism is arranged so that a time delay is possible when using standard flash bulbs, which require a period of time to build up to full intensity. Also immediate flashing is possible when electronic units are used.

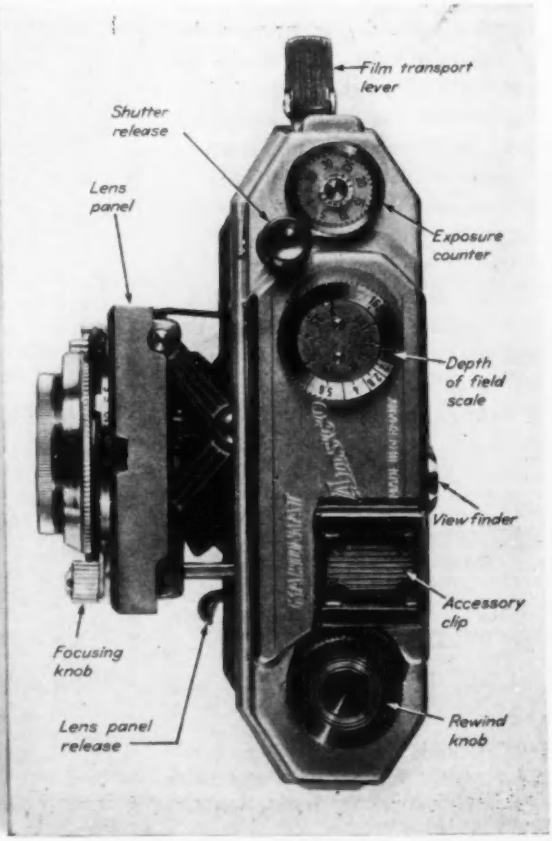
Developed by Agfa Camerawerk, Munich, Germany, U. S. Zone, the design was refined by Ansco, Binghamton, N. Y. to meet American markets. The Karomat is a 35 mm camera with an f:2.0 six element coated lens and leaf type shutter for speeds from one sec to 1/500 sec, time and bulb. Ansco distributes the camera in the United States.

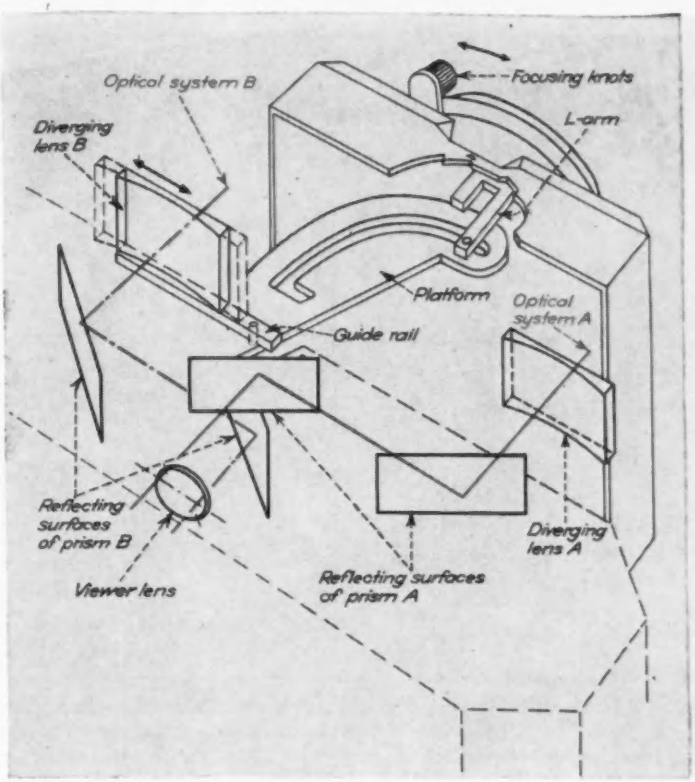


KAROMAT CAMERA (above) has a streamlined metal stamped body that is covered with leather. Exposed parts are chrome plated for corrosion resistance.

CAMERA CONTROLS (right) are positioned for fast operation. Film transport lever is spring loaded so that it automatically returns to its initial position. Focusing range is from 3 ft to infinity.

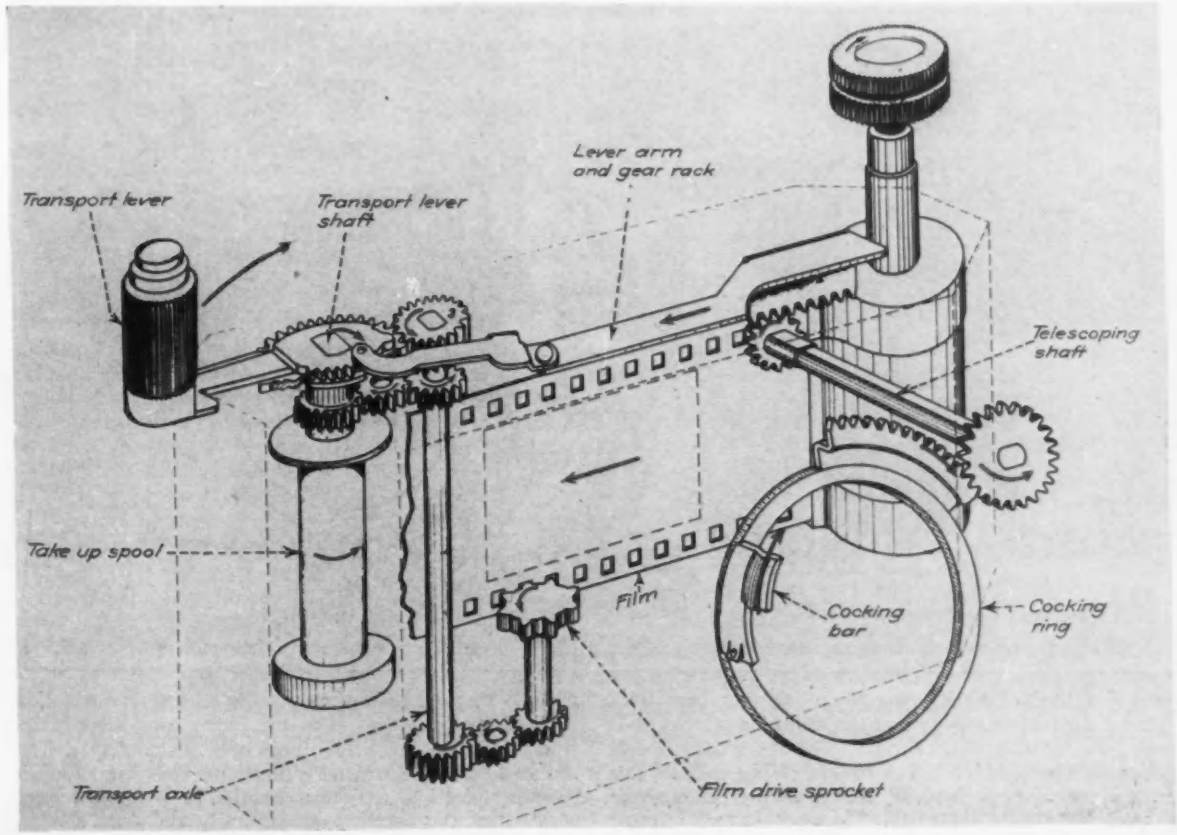
COMBINED FILM TRANSPORT and shutter cocking mechanism (p. 167) permit sequence photography. (A) To move film one frame, transport lever rotates 90 deg. Gearing transmits the rotation to drive sprocket which engages the film perforations. Take-up spool is friction coupled and driven through an idler by a pinion on the transport axle. (B) At the same time, transport lever rotation is transmitted by arm and gear rack to a telescoping shaft (which extends or contracts as the lens mount is moved). This shaft carries pinion that meshes with cocking ring so movement of the transport lever causes the shutter ring to rotate and the cocking bar moves up to set the shutter.



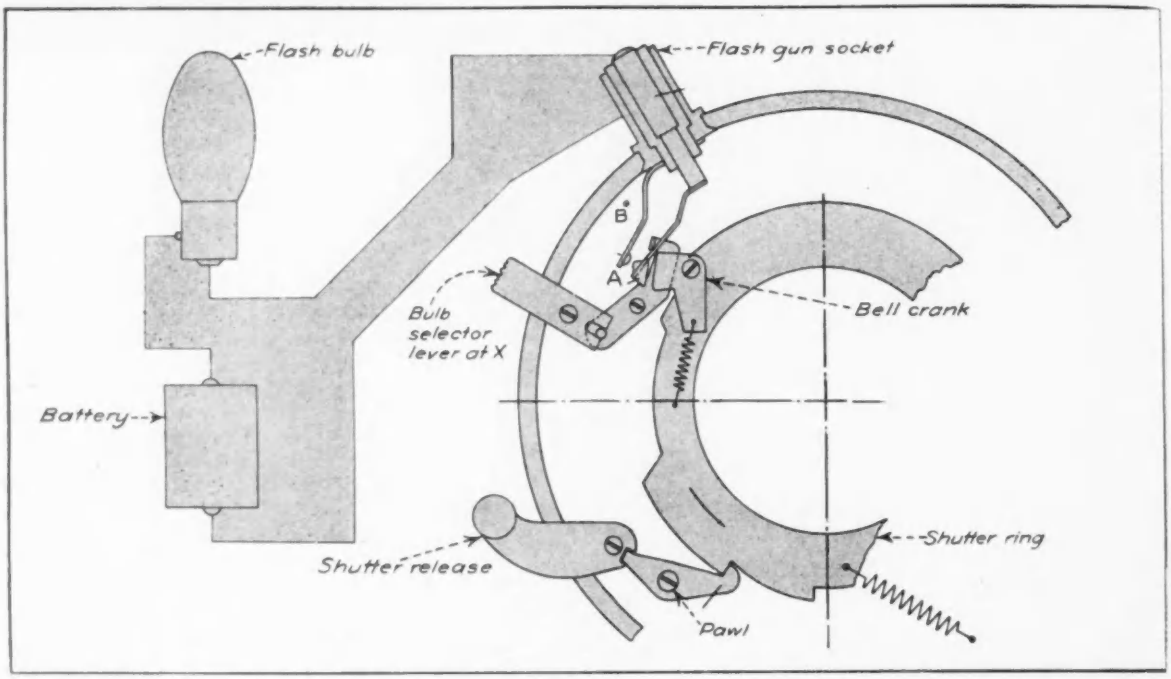


COMBINATION RANGEFINDER and viewfinder speed up focusing. Unit consists of two optical systems (A and B) brought together in viewer lens. Each system is composed of a diverging lens and a prism. Image as seen through viewfinder is divided horizontally in the middle: upper portion is viewed through optical system A; lower portion is viewed through system B. Movement of focusing knob causes L-arm to move in the direction of the optical axis, and since the arm engages in a slot in platform on which lens B is mounted, the platform is moved horizontally changing position of lens B. When upper and lower images line up, camera is in proper focus. The focusing knob is geared to lens mount so that it also moves picture-taking lens.

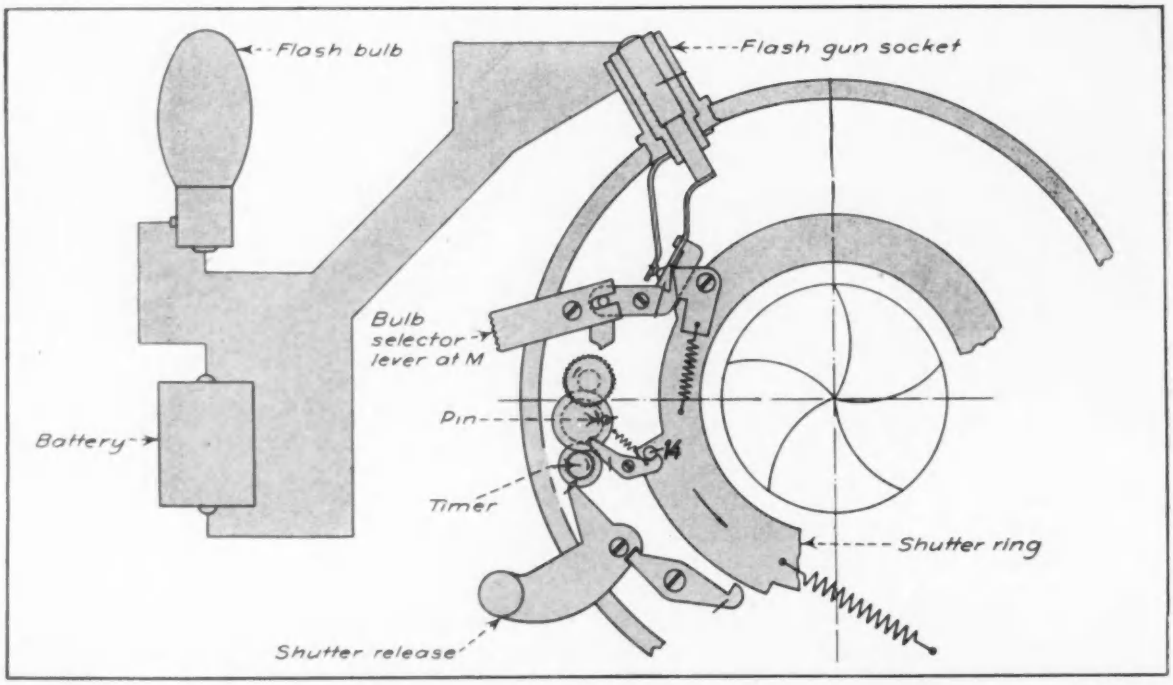
(*continued on next page*)



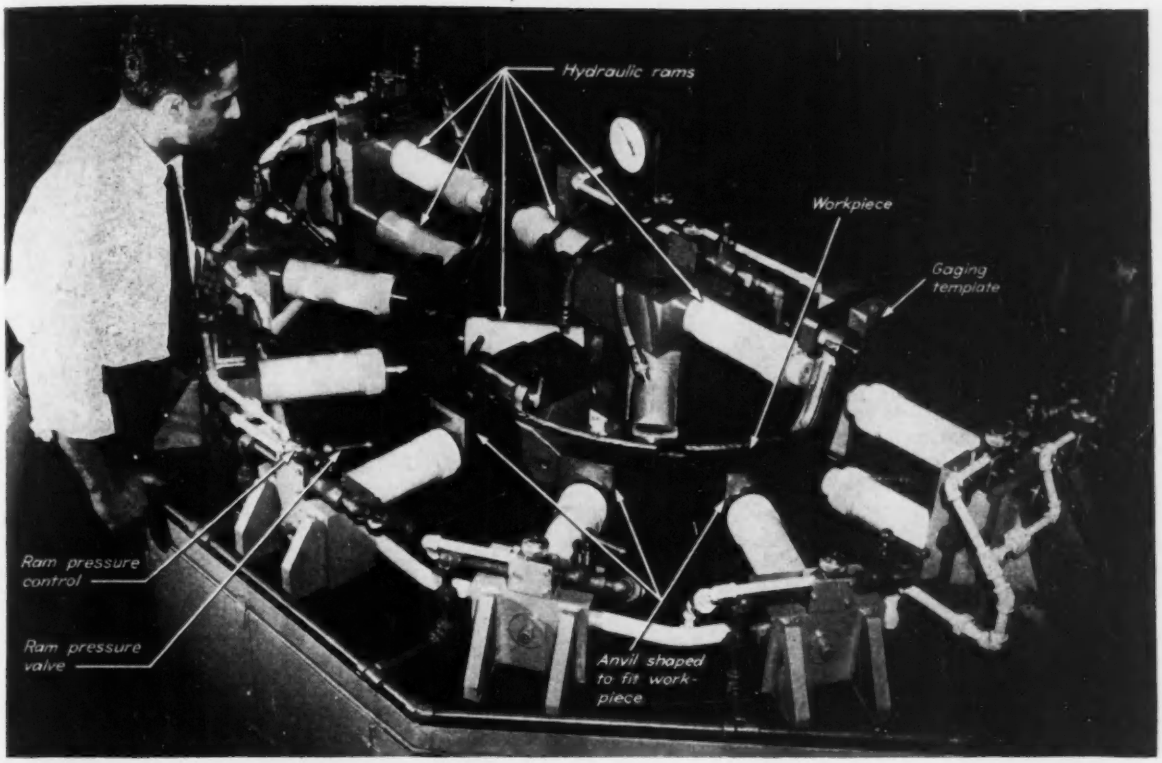
Karomat Camera (continued)

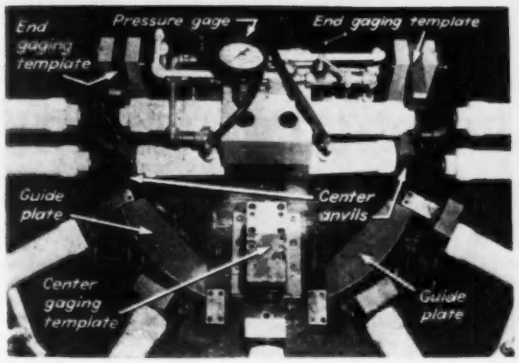


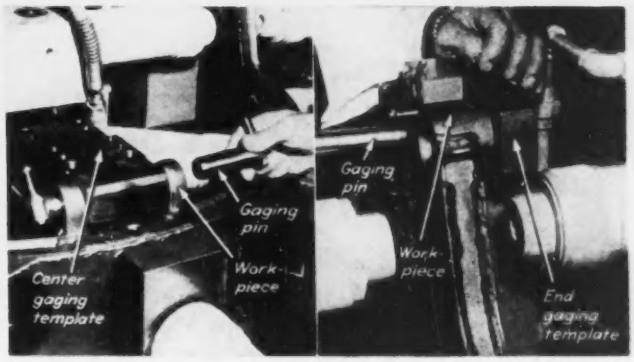
FOR ELECTRONIC FLASH EQUIPMENT with no delay action, shutter is set like this by moving bulb selector lever to the X position. When shutter is released, pawl releases shutter ring. The spring pulls ring around to open the shutter leaves and the bell crank which is connected to the ring strikes contact A and presses it against contact B to close circuit. With this arrangement, opening of shutter leaves and closing of circuit takes place simultaneously.



WITH FLASH LAMPS type M and S that burn with delayed flash action, opening of the shutter is delayed until flash lamp develops full intensity. This schematic drawing shows the shutter at moment of release. When bulb selector lever is moved to position M, shutter release closes circuit to ignite bulb in the same manner as when set for electronic flash. But a pawl (part of mechanism released for operation by bulb selector lever) stops the shutter ring after it has closed the circuit and before it can open shutter leaves. The shutter release also actuates a timer that runs for 16 milliseconds and drives a pin into position to release the pawl so that ring can complete its movement and open shutter.







OPERATOR (top) varies pressure acting on each ram so that the rams slowly press work piece until it conforms to shape of guide plates. Center anvils and rams are mounted on swivels so they can rotate through the complete angle of the saddle which is more than 180 degrees. GAGING (bottom) is done on the machine by inserting gaging pins through the locating orifices of the workpiece into the gaging templates. If the pins enter freely and the upright surface of the saddle is vertical, the unit passes inspection. If the pins cannot be inserted freely, additional corrective pressures are applied.

Hydraulic Rams Straighten Saddles

To simplify the straightening operation on welded jet engine nacelle "saddles," tool engineers of the Bell Aircraft Corporation, Buffalo, N. Y., designed a battery of 13 hydraulic rams that straighten and then gage the part in one-third the time formerly required. Previously, the company straightened the saddles in a 50-ton hydraulic press; but after each application of pressure to an area, the part had to be removed from the press, inserted in a line-up fixture, checked with gages, and then replaced in the press for additional straightening. The new machine supplies pressures up to 3,000 psi to shape the SAE 4130 steel saddle. A skilled operator is required since each ram is adjusted separately, and the straightening is done a little at a time.

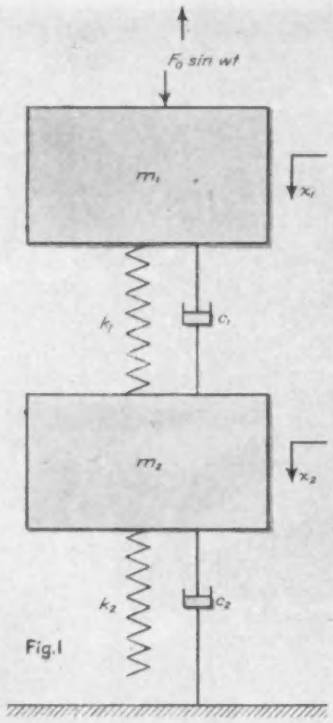


Fig. 1

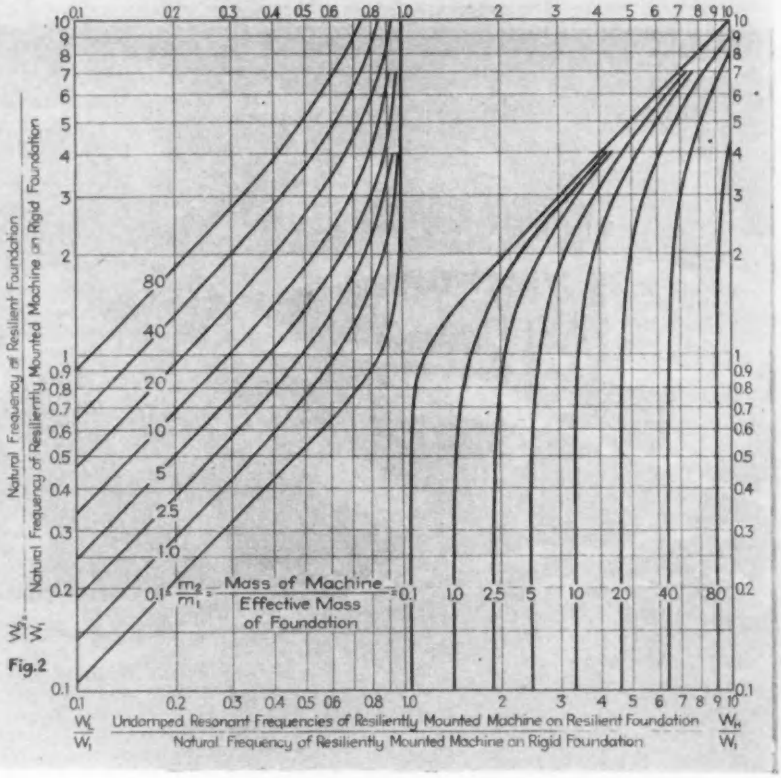


Fig. 2

Effects of Resilient Foundations

A resilient foundation can assist or counteract the effects of vibration mounts, depending on the characteristics of the installation. For most base-mounted machines, the equations and charts presented in this article can be used to determine which condition will prevail for a given case.

HARRY HIMELBLAU, JR.
Armour Research Foundation

SOME ROTATING and reciprocating machines are so installed that noise and vibration must be held to an absolute minimum. In such applications, resilient mounts are frequently placed between the machine and the foundation structure. The mounts that are used must have characteristics suited to the vibrational properties of the machine and the selection should be based on the principles discussed in the June 1952 issue of PRODUCT ENGINEERING.

When choosing mounts, however, it is usually assumed that the foundation structure is rigid. In many cases this assumption must be modified, particularly when the machine and the mounts are installed on I-beams or channel frameworks. Such resilient foundations can either improve isolation or cause increased transmission. To determine which condition will prevail, the transmissibility characteristics of the machine and foundation acting as a unit must be analyzed.

Fortunately, it is not always necessary to consider all three of the transmissibilities. For many base mounted machine-foundation combinations, represented diagrammatically in Fig. 1, only the vertical transmissibility or ratio of the vertical transmitted force from the foundation to the impressed vertical force of the machine need be evaluated. In such cases, the following characteristics must be determined:

k_1 = vertical dynamic spring rate of the resilient mounts
k_2 = vertical effective spring rate of the resilient foundation
c_1, c_2 = damping coefficients of the mounts and the foundation
m_1 = mass of the machine
m_2 = effective mass of the foundation
w = impressed frequency, radians per unit time

Referring to Fig. 1, the sum of the forces on each of the two masses is:

$$Fm_1 = F_o \sin wt - k_1 (x_1 - x_2) - c_1 (\dot{x_1} - \dot{x_2}) = m_1 \ddot{x_1}$$

$$Fm_2 = k_1 (x_1 - x_2) + c_1 (\dot{x_1} - \dot{x_2}) - k_2 x_2 - c_2 \dot{x_2} = m_2 \ddot{x_2}$$

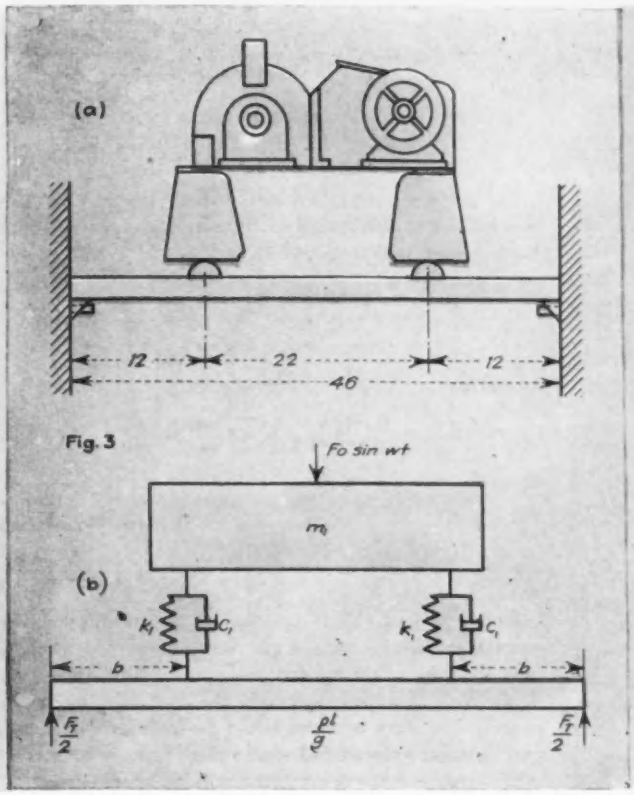


Fig. 1—Isolation solutions for base-mounted machines which can be represented diagrammatically as shown can be checked for the effects of resilient foundations by the equations and graphs that follow. Similar analysis can also be developed for those installations in which horizontal and/or moment transmissibilities are present.

Fig. 2—Graphical solutions for the undamped resonant frequencies expressed by Eq. 2 which is derived below: The family of curves that appear at the left hand portion of the graph refer to the lower frequency ratio, ω_L/ω_1, whereas the curves at the right hand section of the graph give ω_H/ω_1, the higher frequency ratio.

Fig. 3—Compressor shown in (*a*), is suspended on two steel channels between two rigid walls. Schematic, (*b*), indicates that the foundation structure differs from that shown in Fig. 1 which was used to derive Eq. 1. Curves *A* and *B* in Fig. 4 show that the effects on transmissibility, however, are usually small enough to neglect.

on Vibration Isolation

Solving these two equations simultaneously, the vertical transmissibility is:

$$T_Z = F_T/F_o = \left\{\left[1+\left(2\,\frac{c_1}{c_{c1}}\,\frac{w}{w_1}\right)^2\right]\cdot\left[1+\left(2\,\frac{c_2}{c_{c2}}\,\frac{w_1}{w_2}\,\frac{w}{w_1}\right)^2\right]\cdot\left[\frac{w_2}{w_1}\right]^4\right\}^{1/2} \div \left\{\left[\left(\frac{w}{w_1}\right)^4-\left(\frac{w_2^2}{w_1^2}+\frac{m_1}{m_2}+1+4\,\frac{c_1}{c_{c1}}\,\frac{c_2}{c_{c2}}\,\frac{w_2}{w_1}\right)\cdot\left(\frac{w}{w_1}\right)^2+\left(\frac{w_2}{w_1}\right)^2\right]^2+\left[2\,\frac{w}{w_1}\right]^2\cdot\left[\left(\frac{c_1}{c_{c1}}\,\frac{m_1}{m_2}+\frac{c_1}{c_{c1}}+\frac{c_2}{c_{c2}}\,\frac{w_2}{w_1}\right)\left(\frac{w}{w_1}\right)^2-\left(\frac{c_1}{c_{c1}}\,\frac{w_2}{w_1}+\frac{c_2}{c_{c2}}\right)\frac{w_2}{w_1}\right]^2\right\}^{1/2} \quad (1)$$

where $w_1 = \sqrt{\frac{k_1}{m_1}}$, natural frequency of the resiliently mounted machine

$w_2 = \sqrt{\frac{k_2}{m_2}}$, natural frequency of the resilient foundation

$c_{c1} = 2m_1w_1$, critical damping coefficient of the resiliently mounted machine

$c_{c2} = 2m_2w_2$, critical damping coefficient of the foundation

Neglecting damping, two resonant frequencies can be determined by equating the denominator of the transmissibility equation to zero. These are

$$\frac{w_{H,\,L}}{w_1} = \left[\frac{1}{2}\left[\left(\frac{w_2}{w_1}\right)^2+\frac{m_1}{m_2}+1\right] \pm \left\{\frac{1}{4}\left[\left(\frac{w_2}{w_1}\right)^2+\frac{m_1}{m_2}+1\right]^2-\left(\frac{w_2}{w_1}\right)^2\right\}^{1/2}\right]^{1/2} \quad (2)$$

where w_H is the higher resonant frequency and w_L is the lower one.

The graphical solution to Eq (2) is plotted in Fig. 2. The lower frequency is given by the family of curves at the left, and the higher ratio by the curves at the right. To illustrate how these curves can be used, consider the following example:

A three-cylinder one hp refrigeration compressor operates at 1450 rpm. The machine weighs 125 pounds and has the base dimensions shown in Fig. 3. For lack of suitable floor space, the unit is suspended on two steel channels between two walls. Each channel is fastened to the wall with a bracket. Since the unit is located near precision measuring equipment, resilient mounts are installed under the compressor to get optimum vibration reduction.

With the weight of the unit equally distributed on all

four legs, 3 x 1½ in. channels are chosen having the following characteristics:

Weight per unit length: $\rho = 4.1$ lb/ft
Moment of inertia: $I = 0.20$ in.^{4}
Modulus of elasticity: $E = 29 \times 10^6$ psi

The damping of the beam is small enough to be neglected. Its natural frequency is given by

$$\omega_2 = \frac{\pi_2}{l^2}\sqrt{\frac{EIg}{\rho}} = \frac{\pi^2}{(46)^2}\sqrt{\frac{29 \times 10^6 \times 0.20 \times 386}{\left(\frac{4.1}{12}\right)}}$$

$$= 377 \text{ radians/sec}$$

Four rubber mounts are selected having a natural frequency of 630 cpm under the 125 pound load and a damping coefficient of 5 percent of critical damping.

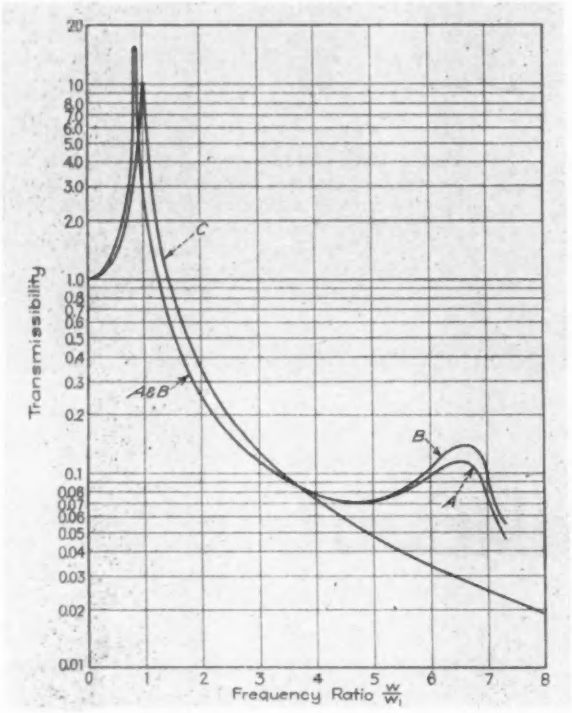


Fig. 4—Comparison of three methods of computing the vertical transmissibility of the compressor in Fig. 3. Curve *A* relates to Fig. 1 and Eq. (1); *B* is based on Fig. 3b and Eq. (3); and *C* is for a rigid foundation.

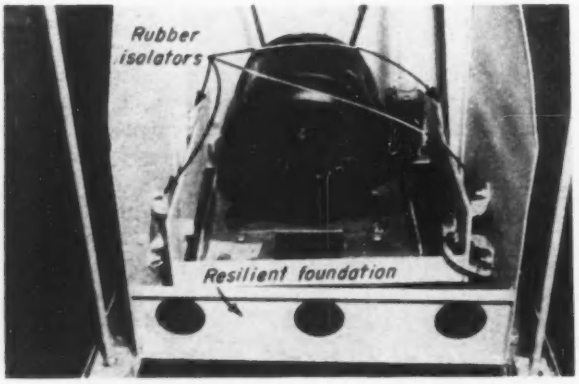


Fig. 5—A ceiling-mounted blower unit, with an isolated motor base on a resilient frame.

Changing the units of the natural frequency to radians per second:

$$\omega_1 = \frac{2\pi}{60} \times 630 = 66 \text{ radians/sec}$$

For each beam, the machine mass is given by

$$m_1 = \frac{125}{2 \times 386} = 0.162$$

By using a method similar to that presented by Timoshenko, the effective mass of the simply-supported equally-loaded beam is determined as:

$$m_2 = \frac{\rho l}{4g \sin \frac{\pi b}{l}} = \frac{\left(\frac{\ }{12}\right)46}{4 \times 386 \sin\left(\frac{12}{46}\pi\right)} = 0.0139$$

Therefore

$$\frac{m_1}{m_2} = \frac{0.162}{0.0139} = 11.6, \text{ and } \frac{w_2}{w_1} = \frac{377}{66} = 5.7$$

From Fig. 2, the resonant frequencies are

$$\frac{w_L}{w_1} = 0.85 \qquad w_L = 0.85 \times 66 = 56 \text{ radians/sec}$$

$$\frac{w_H}{w_1} = 6.9 \qquad w_H = 6.9 \times 66 = 455 \text{ radians/sec}$$

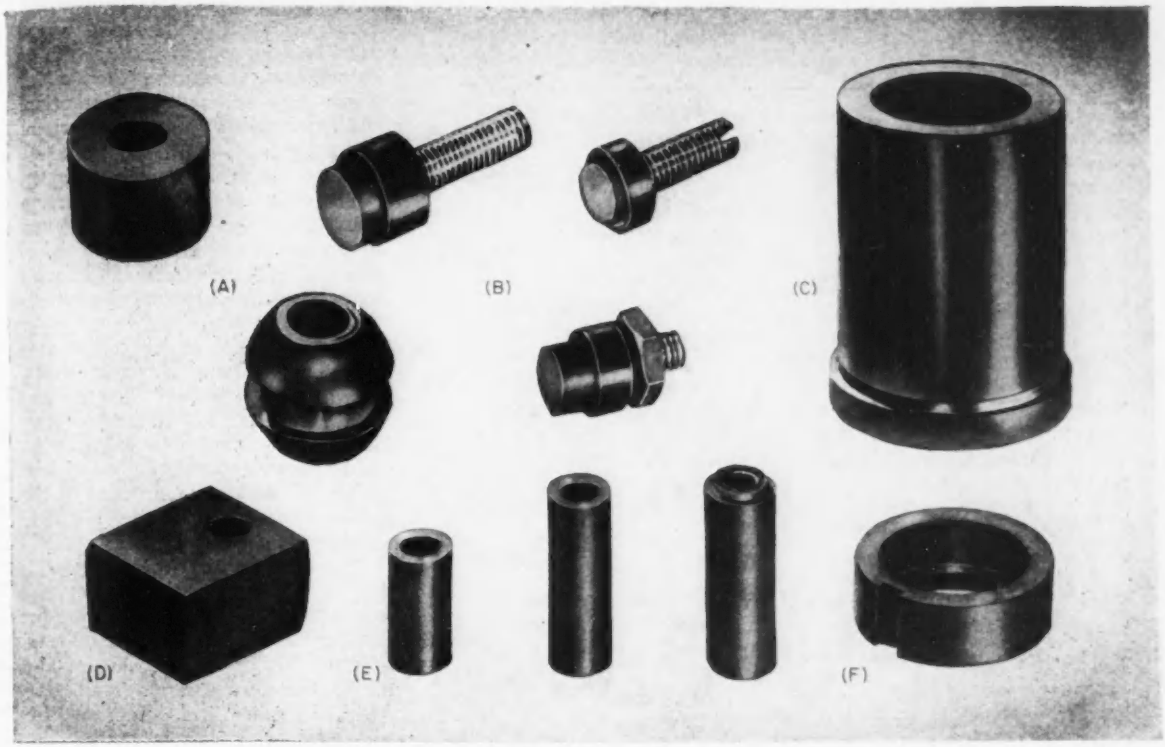
Since the compressor operates at 1450 rpm, which is equivalent to 152 radians per second, vertical vibrations excited at the rotational frequency are sufficiently isolated. With three cylinders, however, the unit also has an impressed frequency of three times the rotational frequency, or 456 radians per second. Since this is nearly equal to the higher resonant frequency, vibration isolation is materially sacrificed. The transmissibility can be reduced by choosing beams with a different stiffness so that a resonant frequency of the system does not coincide with an operational frequency. This will reduce total vibration transmission, resulting in better performance.

If a more detailed analysis is necessary, a transmissibility curve can be plotted, as shown in Fig. 4. Curve *A* is plotted from the vertical transmissibility formula presented above. Curve *B* is based upon a rigorous analysis of the beam structure shown in Fig. 3 (b). This formula is

$$T_Z' = \left\{\left[1 + \left(2\frac{c_1}{c_{c1}}\frac{w}{w_1}\right)^2\right]\left[\left(1 - \frac{\pi}{8}\right)^2\left(\frac{w}{w_1}\right)^2 - 2\left(1 - \frac{\pi}{8} - 2\frac{c_1^2}{c_{c1}^2}\right)\left(\frac{w_2}{w_1}\frac{w}{w_1}\right)^2 + \left(\frac{w_2}{w_1}\right)^4\right]\right\} \div \left\{\left[\left(\frac{w}{w_1}\right)^4 - \left(\frac{w_2^2}{w_1^2} + \frac{m_1}{m_2} + 1 + 4\frac{c_1}{c_{c1}}\frac{c_2}{c_{c2}}\frac{w_2}{w_1}\right)\cdot\left(\frac{w}{w_1}\right)^2 + \left(\frac{w_2}{w_1}\right)^2\right]^2 + \left[2\left(\frac{w}{w_1}\right)^2\cdot\left(\frac{c_1}{c_{c1}}\right)\frac{m_1}{m_2} + 1\right) + \frac{c_2}{c_{c2}}\frac{w_2}{w_1}\cdot\left(\frac{w}{w_1}\right)^2 - \left(\frac{c_1}{c_{c1}}\frac{w_2}{w_1} + \frac{c_2}{c_{c2}}\right)\left(\frac{w_2}{w_1}\right)^2\right\}^{1/2} \quad (3)$$

Curve *C* is constructed from the single degree of freedom equation, e.g., assuming that the beam foundation is rigid.

The isolating performance predicted by the analysis based on a rigid foundation and that predicted by the resilient foundation analysis are readily compared by these curves. The transmissibility peak due to the second resonant frequency can be very important when there is a large exciting force operating near this frequency. It is apparent that the effect of foundation resilience must be considered in the design and selection of a vibration-isolating system to insure effective isolation.



(A) Small bearings of copper or babbitt impregnated carbon have good strength and outstanding functional characteristics. (B) Silver and copper impregnated carbon are used for switch contacts as shown. (C) This metal impregnated carbon journal bearing for a large baking machine resists high temperatures and is self lubricating. (D) Copper, silver and cadmium impregnated carbon electrical contacts, such as the one shown above show high resistance to fusing and sticking. (E) At left two copper carbolube bearings and right a cadmium carbolube roller contact. (F) Seals of this material are impervious and adaptable to high pressures.

Metal-Carbon Composites

For Mechanical and Electrical Parts

Impregnation of carbon with molten copper, silver or cadmium produces a composite material with mechanical and electrical properties not obtainable in the individual ingredients. Improved processing has increased durability and lowered cost.

E. P. EATON, JR.
The Carbone Corporation

GRAPHITE OR CARBON impregnated with metal to a content as high as 70 percent by weight serves effectively for electrical parts and for bearings, seals, and other mechanical parts where lubrication is difficult, or undesirable, or where service conditions are severe.

Impregnation of carbon with metal is not a new technique, but recent process improvements have made possible a more homogeneous, durable material at reasonable cost. It is now available in many grades incorporated with either babbitt, copper, cadmium or silver.

Since this material is of a composite nature it derives many of its properties from the basic ingredients. The carbon and graphite used have many useful properties for both electrical and mechanical applications. These are:

1. A wide range of friction coefficients.
2. Good electrical conductivity even at high temperatures.
3. Resistance to high temperature. With some special handling, graphite can be heated to 4,500 F without losing strength.
4. Good resistance to chemical attack.
5. Dimensional stability at high and low temperatures, and resistance to thermal shock.
6. Good heat insulation or conduction. According to grade, they are either heat insulators or heat conductors (carbon is a heat insulator and graphite is a heat conductor).

Table I—General Mechanical Characteristics of Babbitt and Copper Impregnated Carbon

Weight	1-3/4 to 3 ounces per cubic inch*
Percentage of metal by weight	35 to 70 percent*
Tensile strength	3,900 to 5,500 psi*
Compressive strength	16,000 to 20,000 psi*
Coefficient of friction	constant and low*
Coefficient of expansion	approximately 1/2 iron or steel
Bearing load pressure	20 to 100 psi on the projected area for best operation*
Speed	1,500 to 7,000 F.P.M., depending on grade*

Minimum wall thickness, inside diameter divided by bearing load press. No wall thickness less than 5/64". Operating temperature for Babbitt impregnated carbon not to exceed 350 F. Copper impregnated material not to exceed 750 F. Bushings should be installed by means of a pressed fit, in a bored or reamed hole.

*Between these limits, according to grades.

Table II—Copper Impregnated Grades for Brushes or Contacts

Copper content percent	Specific resistance ohms/ cu. cm.	Amps./ Sq. In.	Recommended speed	Coeff. of friction	Contact drop	Hardness
40	0.00021	75	5000	Very Low	Low	45
45	0.00018	80	5 to 6000	Very Low	Very Low	47
50	0.00015	90	5 to 6000	Low	Very Low	48
51	0.00009	105	6 to 7000	Very Low	Very Low	45
57.5	0.00005	115	5 to 6000	Very Low	Very Low	38
61	0.00004	118	5 to 6000	Very Low	Very Low	38
63	0.00003	122	6 to 7000	Very Low	Very Low	35

7. Low density—a fourth that of iron.

8. Ease of molding and machining and self-lapping.

Three forms of carbon or graphite are used. The first is carbon itself, which is an amorphous material produced from petroleum coke, retort coke or lamp black. The carbon is finely ground, mixed with tar or pitch, extruded, and then baked at approximately 2,000 F. It is a hard material with a high coefficient of friction and when impregnated with metals makes an exceptionally durable composite.

The second form is artificial graphite. This is made by heating carbon to 4,000 F in an electric furnace, which artificially turns amorphous carbon into crystalline graphite. Artificial graphite differs from carbon in that it is softer, more resilient and a better conductor of current. It has a lower coefficient of friction and a lower specific electrical resistance. When impregnated with metal, it provides excellent self-lubricating properties.

The third form of carbon is natural graphite, which is crystalline in structure and at the same time possesses a natural lubricating quality. Graphite material for impregnating is made by pressing ground up natural graphite flakes with a binder and then baking. A high degree of porosity can be obtained with some graphite grades, furnishing a good impregnating medium. The hardness of natural graphite is low but it has a low coefficient of friction and can be used at high speeds. In the impregnated form, it has many electrical applications.

Metals Used

Babbitt metal, a composition of lead and tin combines with any one of the three forms of carbon to give a completely oil-less self-lubricating durable bearing material. Babbitt is the usual liner for journal bearings. In its generally used form, however, oil or grease must be used for lubrication. With the carbon no outside lubricant is required.

When impregnated with copper, carbon provides good current carrying capabilities since carbon, graphite and copper are all good conductors of electricity. This material also can be used for bearings and parts for temperatures up to 750 or 800 F.

Cadmium impregnated carbon also has some outstanding characteristics. Bearings and parts made from this material show long life and, where current must be carried in a somewhat oxidizing atmosphere, it is the best choice. Cadmium oxide is one of the few oxides that is a better electrical conductor than the original metal.

The silver impregnated material is the best conductor of electricity and has the lowest friction combination for bearings and parts. Its durability is excellent. With new techniques and by keeping the bearing wall thin (backed with steel or iron for strength) its cost is not excessive.

The finished material, marketed under the name of Carbolube, differs from carbon in that it is impervious to liquids and gases. Also, unlike many carbon and graphite grades, it is strong and hard, has had a low rate of wear and its running friction is lower than any of its corresponding grades of graphite or carbon. Its machinability is excellent, it is easier to hold to close tolerances than the basic materials and is self-lapping. Table I lists some mechanical and electrical properties.

Applications

Metal impregnated carbon's main use is for mechanical parts such as bearings, rings, valves, pistons, slides, and similar products.

Bearings—In all cases bearings require absolutely no lubrication and are advantageous for the following service conditions:

1. Where high or low temperatures are encountered. That is, where oil carbonizes or solidifies such as on stokers, hot conveyors or refrigeration machines.

2. Where the fumes of oil or volatile lubricants are undesirable either from the cleanliness or fire hazard standpoint.

3. Where heat would cause other self-lubricating material to dry up their reservoirs of lubricant.

4. Where oil lubrication cannot be

applied such as in food or textile machinery, air compressors, etc.

5. Where bearings or parts are inaccessible such as marine equipment, telephone switchboards, water and gasoline meters.

6. Where bearings or parts are submersed in liquids and therefore lubrication cannot be applied such as on meters, pumps and mixers.

7. Where constant friction must be maintained such as on testing apparatus, precision instruments, electric equipment.

Seal Rings—Seal rings fabricated from this material are completely impervious and adaptable to drop-tight seals at high pressures and for refrigeration, air and gas seals.

Certain grades are also used for fluid drives, torque converters, pumps or in corrosive liquids and gases.

For special applications, they can be machined to 0.0005 in tolerance and lapped and polished to within a few millionths of an inch of flatness.

This metal-carbon composite can be used for guide slides for presses, pistons, piston rings, valve parts, thrust washers, molds and rollers.

Electrical Uses

In the electrical field metal impregnated carbon is used primarily for brushes and contacts.

Brushes made from copper impregnated stock are used for both low voltage d-c generators, synchronous motors and wound rotor induction motors. They are available in grades with current carrying capacities ranging from 75 to 122 amps per sq inch. In operation these grades produce a film that is unusual for a relatively high metal content brush material. They give long life and run at low temperature because of their low friction coefficient. Normally with heavy metal brushes the build up of temperature on a commutator or ring is generally due to friction. These brushes also improve efficiency by reducing the friction losses which are usually the biggest item in the total losses on the ring or commutator. The approximate characteristics on seven grades are listed in Table II. Silver impregnated brushes are widely used for synchromotors and electronic assemblies.

Carbon impregnated with copper or silver shows greater resistance to fusing and sticking for contacts than other metal graphite combinations and here again numerous grades are available for specific applications.

Silver-carbon is advantageous for low resistance switch and signal contacts where fusing and sticking must be avoided at all costs. Both copper and silver composites are adaptable to most contacts for high current and low loss switches.

The cadmium impregnated material also has its advantages for contacts as its oxide is a better conductor than the metal itself. All three materials can be mounted in brass holders by silver soldering or press fitted or shrink fitted to make contacts for switch gear and control apparatus.

Copper or silver impregnated carbon can act as current carrying bearings or rings where current must be transferred from a shaft to a stationery piece, or from one rotating member to another rotating at a different speed. They serve as bearings and carry current with low losses simultaneously.

Design Factors

Since these materials are made from stock or molded parts, all that is needed in most cases is the specification of the finished part. However, this impregnated carbon has certain characteristics and these should be taken into account by the engineer before specifying dimensions and use of the material. In general, as a bearing it should be used against shafting, steel, or hardened metals. The smaller the shaft the higher the allowable pressures on the projected area. Also, the faster the rotation of the shaft, the lower the allowable pressure on the bearing. In any case, any part working against this material must be smooth and free from nicks.

Metal impregnated carbon in all its forms is very hard and must be cut with high speed steel, tungsten carbide or diamond tools, and usually the finish is accomplished with grinding machines. Therefore, designers should eliminate difficult tolerances and complicated designs wherever possible. Thin complicated sections and fine tapped holes, threads, keyways, corrugations, are difficult to machine. Some of these are possible but special machining increases the cost of the part more than it would in steel or other metals. It is therefore, desirable that the part be kept as simple as possible and that the machining necessary be done on the adjacent parts when feasible.

Mechanically the material is strong in compression, but wherever thin sections are used, it should be backed up by cast iron, brass or steel. High tension and impact stresses should be avoided because the material is fairly brittle. Parts can be assembled by press fit or shrink fit. They can also be copper plated and soft soldered. Tolerances, press fits and recommended clearance are shown in Tables III and IV.

Machining practice for impregnated carbon is similar to that used for metals. It can be drilled with carbide drills at high speed, machined on the lathe, or milling machines, or planers. Since the dust from this material is abrasive and the material is so hard the materials manufacturers prefer, in most cases, to handle machining of the material and it is generally offered only as a finished piece for incorporation into a machine or product.

Table III—Press Fit Recommendations

From 1" to 2" O.D.	Plus 0.0015 to 0.002 inches
From 2" to 4" O.D.	Plus 0.002 to 0.003 inches
From 4" to 6" O.D.	Plus 0.003 to 0.004 inches

Most any shaft, such as cold rolled, hardened or stainless steel, will perform satisfactorily, providing the surface is smooth.

Table IV—Minimum Clearance Between Shaft and Bushing

Diameter of shaft up to 1/2 in.	0.0015 in. clearance
Diameter of shaft up to 1 in.	0.002 in. clearance
Diameter of shaft up to 2 in.	0.0025 in. clearance
Diameter of shaft up to 3 in.	0.003 in. clearance
Diameter of shaft up to 4 in.	0.0035 to .004 in. etc.

The inside diameter of the bushing should be reamed or ground, to allow for the above clearance. In other words, if the bushing closes or contracts 0.001 in. after being pressed into the housing, allowance should be made by machining the bore of bushings 0.001 in. larger than the above mentioned clearance recommendation.

Recommended Practices for Designing

EXPERIENCE IN THIS FIELD has proved that faulty design is responsible for more difficulties than faulty processing. Considerations that do not enter into ordinary sheet metal fabrication are vital to good porcelain enameling. For example, to be certain that a part can safely withstand the high firing temperatures, such factors as kind of base metals, gage of metal, size and shape of piece, method of forming, rigidity, holes for hanging, etc. must be considered. Selection of the proper gage metal cannot be overemphasized. Although no hard and fast rules can be made, the table below can be used as a guide for parts of moderate size to be finished in white or light colors, where only moderate rigidity and flatness are required. In general, it is better to err on the side of too heavy a metal than to use one too light. The first case will cause little or no trouble during the enameling or mounting, the only loss being the extra amount of metal required. When the metal is too light, however, warpage, sagging, hairlining

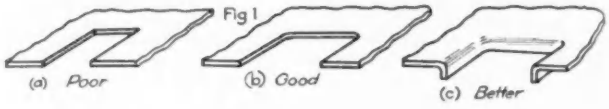


Fig. 1—Avoid square corners in openings to prevent porcelain from hairlining in corners. For white or light colors, min. radius of flanges in (c) should be 3/16 in. and min. flange depth ¼ in. With dark colors, 9/64 is min. flange radius.

Fig. 2—Raw edges are undesirable on finished parts since porcelain will burn off the edges. Flanges should be turned down as shown in Fig. 1 (*c*) whenever possible.

Fig. 3—Use equal cross sections so that when parts are heated and cooled, expansion and contraction will be uniform, and warping and chipping of porcelain because of strains in the metal will be avoided.

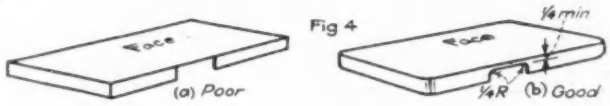


Fig. 4—Wrong method of making a flange cut-out is shown in (*a*). Chipping and hairline will occur on the face. Method illustrated in *(b)* is correct. Corners of rectangular parts should have generous radius with sharp corners, annealing may be required to prevent recrystallization during firing.

Fig. 5—Avoid welding on exposed surfaces if possible. When stiffening braces are required, they should be skeletonized to minimize weight and insure proper firing. Weld spots must be smoothed off or indentures will show.

Fig. 6—Do not use square notched corners in panels with flanges. Notching at 45 deg, (*b*), is preferred if parts are formed on press brake. When production volume warrants forming and blanking tools, the method in (*c*) can be used.

Fig. 7—Avoid turned-under flanges. If part is dipped, excess enamel cannot drain; if part is sprayed, under side of flange will be difficult to reach; and if the part is exposed to moisture, rusting might occur.

Fig. 8—In (*a*), the angle of the vertical flange will change during firing; in *(b)*, support provided by end flange is inadequate. For proper support, $A\text{-}B = 1/3\ F$ as in *(c)* or if *A* and *B* are less than *1/3 F, (d)*, additional support can be provided by the strap that is spot welded to the frame.

Recommended Gages of Metal

Gage No.	Approx. Thickness, in.	Width, in.	Total Area, ft²
24	0.0239	6	0.5
24	—	12	3*
24	—	18	5*
22	0.0299	6	1
22	—	12	3.5
22	—	18	6*
22	—	24	8*
20	0.0359	6	1.5
20	—	12	5
20	—	18	8*
20	—	24	10–15*

* Should be embossed flanged or otherwise suitably reinforced. All parts larger than indicated should be made from 18 gage or heavier metal.

Porcelain Enamel Products

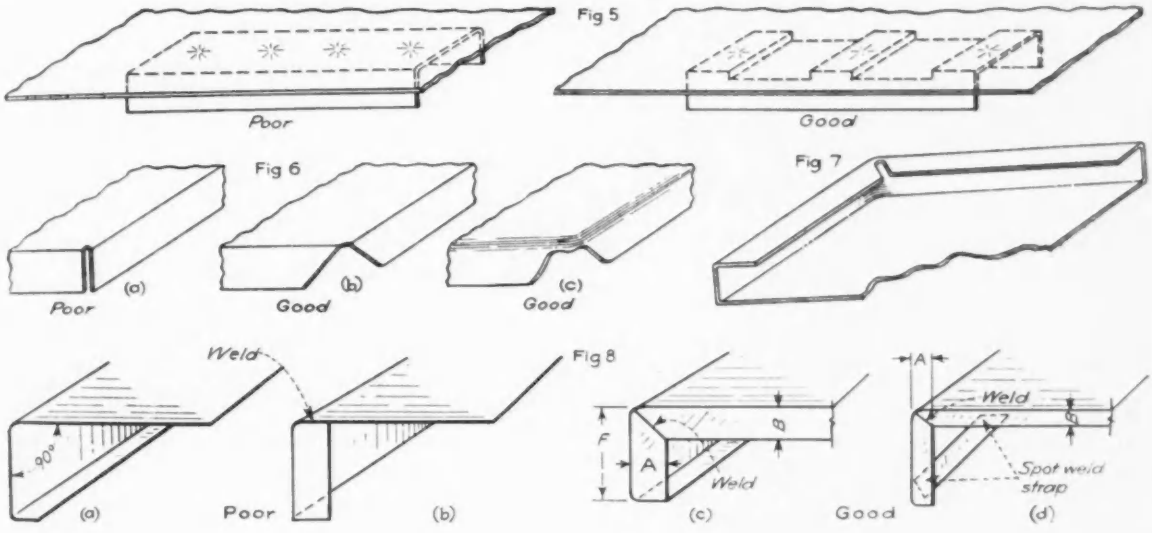
PAUL F. METZ
Crosley Div. Avco Manufacturing Corp.

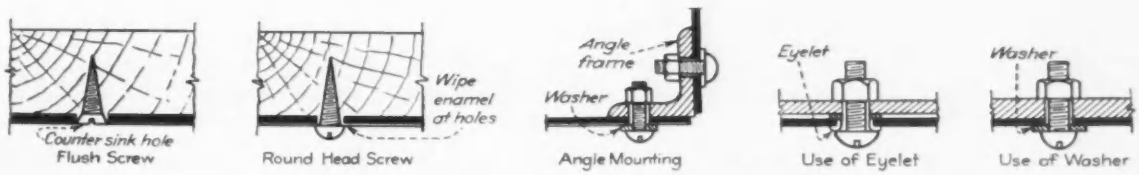
and/or chipping are frequently encountered. Using heavier gages will also help eliminate unequal stress distributions that often result from drawing operations.

The qualities that must be inherent in a good enameling stock are given as follows:

1. Very low carbon content.
2. Freedom from harmful solid or gaseous impurities.
3. Resistance to sagging and warping at enamel firing temperatures.
4. Good welding qualities.
5. Good drawing or working qualities.
6. Good surface texture.
7. Uniformity of composition.

The sketches shown below illustrate recommended industrial design practice and methods of fastening porcelain enamel plates to supporting structures; some of them were supplied by the Porcelain Enamel Institute, Inc. of Washington, D. C.





Methods of Fastening Porcelain Enamel Plates

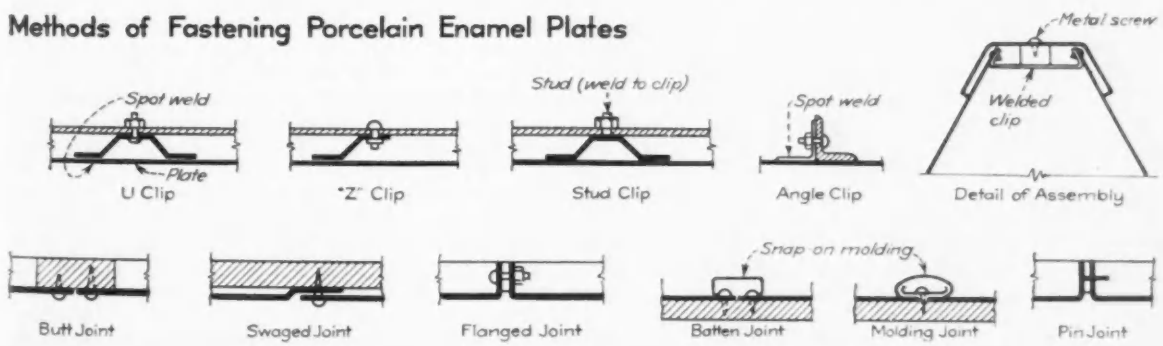


Table I—Description of Miscellaneous Drafting Templates

NO. 17—3/16 in. and 5/16 in. Fluid Fitting Template includes the following AN part numbers:
806 plug; 815 union; 818 coupling nut;
819 coupling sleeve; 821 90 deg elbow;
832 bulkhead union; 833 90 deg bulkhead elbow;
837 45 deg elbow; 6289 nut; 10050 boss.
Overall size of template is 5½ by 7⅛ in.

NO. 18—¼ in. and ⅜ in. Fluid Fitting Template includes same AN part numbers as Template No. 17 but for ¼ and ⅜ in. tube sizes. Overall size of template is 5⅛ by 7 9/16.

NO. 19—⅛ in. Fluid Fitting Template includes same AN part numbers as Template No. 17 but for ⅛ in. tube size.
Overall size of template is 5 by 8 in.

NO. 20—½ in. Fluid Fitting Template includes same AN part numbers as Template No. 17 but for ½ in. tube size.
Overall size of template is 5¾ by 9½ in.

NO. 31—Full Size Nut and Bolt Template includes:
Plain bolt head; AN320 nut; AN365 nut; AN364 nut; 3/32 through ¼ in. round and flush rivets by 1/32nds; No. 6, 8, 10 and ¼ nutplates; spotfaces; threaded assemblies; clevis bolt heads; recessed screw heads; item circle; dash number circle; and pilot hole.
Overall size of template is 5 by 6⅞ in.

NO. 32—Half Size Nut and Bolt Template is the same as Template No. 31 except that half and full size speed nuts are included.
Overall size of template is 4 by 5⅞ in.

NO. 33—Small Size Ellipse Template includes projections of circles to:
30 deg ellipses from ⅛ in. to 1 in. by 1/16ths, then by ⅛ths to 1⅜ in.
45 deg ellipses from ⅛ in. to 1 in. by 1/16ths, then by ⅛ths to 1⅜ in.
60 deg ellipses from ⅛ in. to 1 in. by 1/16ths, then by ⅛ths to 1¼ in.
75 deg ellipses from ⅛ in. to 1 in. by 1/16ths, then by ⅛ths to 1⅜ in.
Overall size of template is 8½ by 11 in.

NO. 34—Large Size Ellipse Template includes projections of circles to:
30 deg ellipses 1⅛, 1⅜, and from 2 through 4 in. by ½ in. increments.
45 deg ellipses 1⅜ and from 2 through 4 in. by ½ in. increments.
60 deg ellipses 1⅛, 1½, 1⅞, and from 2 through 4 in. by ½ in. increments.
75 deg ellipses 1⅜, 1⅞, and from 2 through 3½ in. by ½ in. increments, 3⅞, and 4 in.
Overall size of template is 8½ by 11 in.

NO. 35—Lettering Template includes:
Capital letters; numbers; zone blocks; finish marks; GFE triangles; and dash number circles.
Corners rounded to ⅛, ¼, ⅜, and 1 in. radii.
Overall size of template is 3¼ by 6 5/16 in.

NO. 36—Tooling Template includes various sizes of: Jam nuts; regular nuts; nut profiles; lock screws; cap screws; tooling buttons; center drills; hex bolts and nuts; screws; circles; and radii.
Overall size of template is 5¼ by 6¼ in.

NO. 38—Circle Template includes circles from:
1/16 to ¼ in. dia by 1/32nds.
13/16 to 1 in. dia by 1/16ths.
1⅛ to 1½ in. dia by ⅛ths.
Corners rounded to produce radii from 13/16 to 1 in. by 1/16ths.
Overall size of template is 4 5/16 by 7 13/16 in.

NO. 41—Sheet Thickness Template includes:
Guides for making equidistant lines, straight and curved, spaced by standard aluminum sheet gages 0.025 to 0.375 in. inclusive.
Overall size of template is 2 in. diameter.

Templates of Detail Profiles

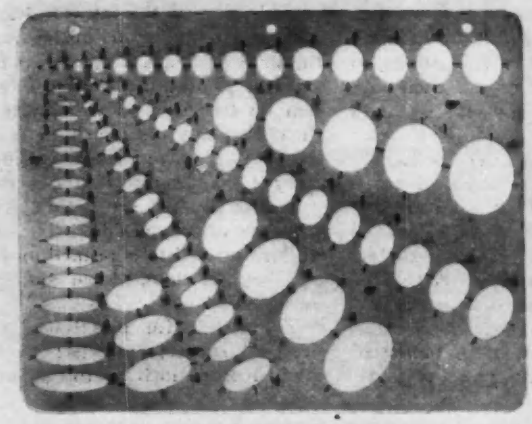
MORRIE HARPER and M. G. CASADY
Design Standards Engineers, Douglas Aircraft Company, Inc.

ADOPTION OF TOOLING PRINCIPLES by the engineering department, or "drawing factory," can do much to offset the present scarcity of experienced engineering personnel. The application of these principles will make possible a better utilization of the talents of the present staff; it also will shorten the time required to train new men in the techniques of preparing an acceptable drawing.

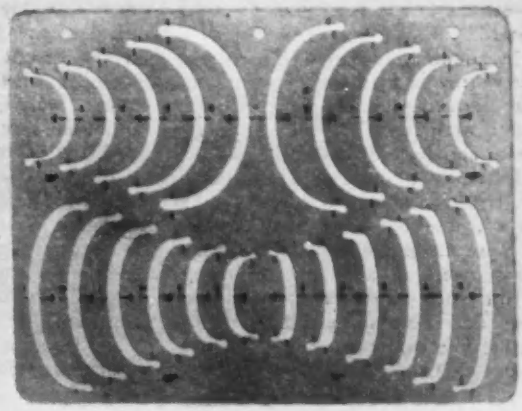
Expanding production requires a larger quantity of drawings, more completely detailed, legible, and more devoid of errors. Many of these drawings are prepared by new engineering employees who have had little training and lack expert skill. In the shop, such drawings must be interpreted by many new employees who also have little training and skill. These men cannot be expected to detect or make allowances for errors or omissions in blueprints. The situation, if not checked, can compound itself until more effort is being made interpreting and correcting drawings than is spent in their original preparation.

How to produce at minimum cost an increasing flow of complete, correct and legible drawings with relatively un-trained engineering personnel, is the problem. The Douglas Aircraft Company has learned that a part of the answer is to furnish this personnel with adequate tooling.

The use of drafting tools and accessories, of course, is not new. Drafting machines, T-squares, compasses, triangles, and French curves are standard equipment in practically every design department. At Douglas, this tooling principle was extended to in-

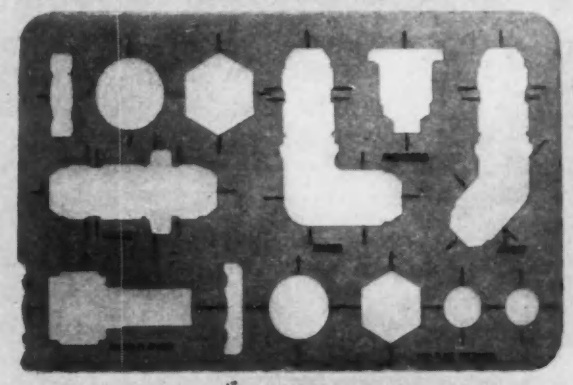


No. 33 Small ellipse template

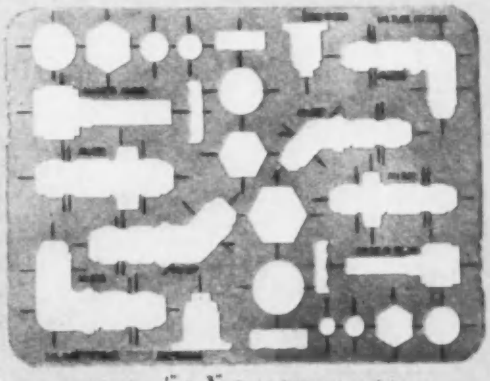


No. 34 Large ellipse template

Fig. 1—Ellipse templates include thirty, forty-five, sixty, and seventy-five degree projections of circles.



No. 19 $\frac{1}{2}$" Fluid fitting template



No. 18 $\frac{1}{4}$" & $\frac{3}{8}$" Fluid fitting template

Fig. 2—Fluid fitting templates that give space required for AN plugs, unions, couplings, and elbows.

Promote Drafting Efficiency

clude a series of templates that permit the rapid and accurate mechanical reproduction of detail shapes. The series of templates, described in Table I and shown in Figs. 1, 2 and 3 was first used in 1942 by the Douglas Aircraft Company.

At that time, the design, planning, tooling and fabricating departments were expanding somewhat as they are now, and adequately trained personnel were not available. In addition, a survey of drafting requirements and practices revealed that the trend in aircraft design was steadily towards more "compactness," and that problems of clearance and interference were becoming critical. Consequently, to determine whether or not the designed space would accommodate the intended equipment and allow access for installation and service, it was necessary on many drawings to detail completely nuts, bolts, rivets, and hydraulic fittings.

Because of the tediousness involved and the need for meeting schedules the tendency was for draftsmen, when outlining such standard parts, to guess at the exact dimensions, to indicate the parts with a center line or to draw them in free hand. To discourage this practice every draftsman was furnished with a complete set of general usage templates. This set includes nut and bolt templates, circle template, ellipse templates, material thickness template and lettering template. Some templates were also distributed on a restricted basis to special groups. Draftsmen in the hydraulic group were given fluid fitting templates, and tool and die draftsmen in the tooling division were given tooling templates.

From an efficiency standpoint the use of these templates has been well justified. Observations show that "board" draftsmen, not using templates, spend approximately ten percent of their total drafting time performing operations that could be done

with templates. Tests show that the use of the templates reduces these operations to one percent of the total "board" time.

In addition, improved efficiency is noteworthy in Planning, Tooling and Manufacturing since these departments were furnished with more accurate and legible drawings.

Introduction of the tool templates has resulted in more airplanes for a given amount of effort. The success of these mechanical aids has inspired the proposal of additional templates of the same type. Possible applications are: Forging templates (draft angles, fillet and edge radii), hat sections, electrical fittings, and sheet metal bend radii and flange height. Whether or not such templates, or others that may be proposed, are furnished to the draftsmen will depend on the results of investigations to determine whether or not their usefulness warrants the tooling and fabrication cost.

All the templates listed in Table I were originally designed and fabricated by Douglas for its own use. They are now being manufactured for resale, under a licensee manufacturers agreement, and are distributed nationally by major drafting supply companies.

The lettering template is fabricated by injection molding green transparent polystyrene 0.050 in. thick. This method of fabrication insures accurate reproduction of the intricate lettering detail. All other templates, except the sheet thickness template, are fabricated by printing the desired information on 0.025 in. clear Vinylite and then blanking on punch press dies. An amber color vinyl coating is sprayed on to protect the printing, provide a pleasing color and make the template more visible. The sheet thickness template is printed on 0.040 in. Vinylite, stamped out and sprayed red.

To provide for pencil lead thickness, all cutouts are offset 13 thousandths of an inch on the radius.

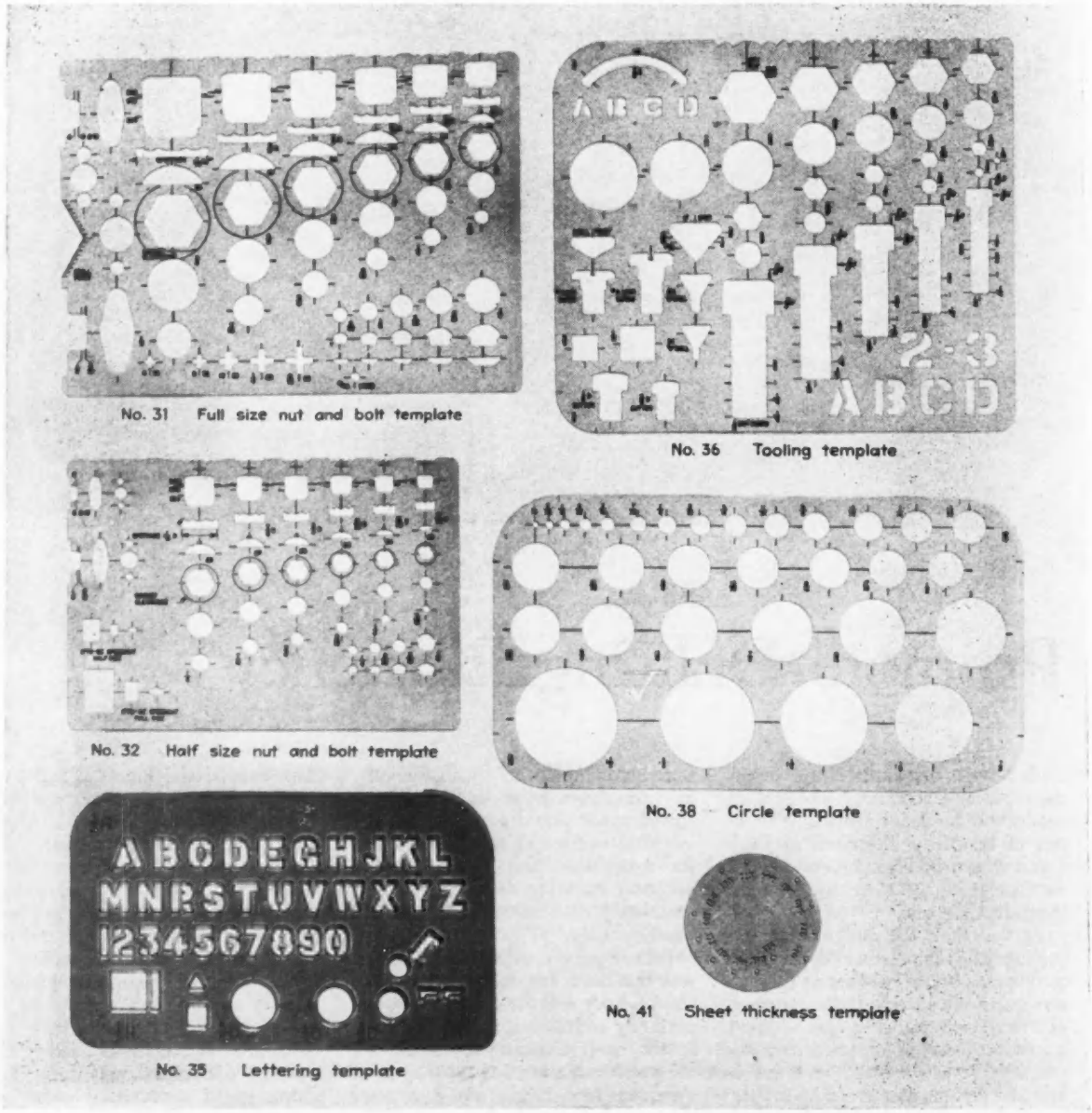

No. 31 Full size nut and bolt template
No. 36 Tooling template
No. 32 Half size nut and bolt template
No. 38 Circle template
A B C D E G H J K L
M N R S T U V W X Y Z
1 2 3 4 5 6 7 8 9 0
No. 41 Sheet thickness template
No. 35 Lettering template

Fig. 3—Templates that facilitate the detailing of fasteners, sheet thickness, circles, and lettering.

How PROSPEROUS Is The USA?

Just how prosperous *are* the people of the United States?

The sole purpose of this message is to help clear up the confusion and controversy that surrounds this important question.

To find out how much prosperity, or material well-being, the people of the United States now enjoy, it is necessary to get answers to these questions:

1. As compared with other times, what is the total amount of goods and services that we have available for our enjoyment?

2. How great, on the average, is the share of each American in this prosperity?

3. How does our prosperity compare with that of other nations?

National Product at Peak

The government statisticians who do the bookkeeping for the nation produce a figure called the Gross National Product. It is supposed to be the total obtained when you multiply the amounts of everything we produce by the prices of everything produced. This year the GNP, as it is commonly tagged, will add up to something like $345 billion.

Since this will be the highest total that GNP has ever attained, some people will acclaim it as evidence that we now are enjoying the greatest prosperity on record.

The GNP, however, is not an accurate yardstick of prosperity. It may go up because of price inflation alone without any increase at all in the output of goods and services. Also the GNP includes very large amounts of goods and services, such as those for the military, which are in fact a result of misfortune rather than of a condition that might properly be called prosperity. Moreover, there is no deduction from the GNP to make allowance for the equipment that is worn out in producing it.

Little Recent Progress

When we make adjustments such as these — to find out how much of our production really is available for the use and enjoyment of the civilian population — the *adjusted* national product since the beginning of World War II comes out about as follows. The effects of price inflation have been removed from these figures.

YEAR	ADJUSTED NATIONAL PRODUCT	
	Billions 1951 Dollars	Index (1946 = 100)
1940	$176.2	76
1946	232.5	100
1947	240.7	104
1948	244.3	105
1949	239.7	103
1950	260.9	112
1951	267.9	115
1952	264.3	114

From this table the fact stands out that progress in raising our level of prosperity has been halting. What progress we have made came in a few dramatic increases before or after a military build-up. Aside from those, the progress has been fairly slow. This year, 1952, it has been particularly discouraging.

Again, when account is taken of the number of people who must share in the goods and services that are available, our progress is even less marked. This is shown by the following table which gives the share of the average American in the national product. This, as the table indicates, is arrived at simply by dividing the total of available goods and services by the population on hand to share in them.

YEAR	POPULATION Millions	ADJUSTED NATIONAL PRODUCT Billions 1951 Dollars	ADJUSTED NATIONAL PRODUCT Per Person
1940	132.0	$176.2	$1,335
1946	141.3	232.5	1,645
1947	144.0	240.7	1,672
1948	146.6	244.3	1,666
1949	149.2	239.7	1,607
1950	150.6	260.9	1,732
1951	154.4	267.9	1,735
1952	156.9	264.3	1,685

Here it is clear that we have made little or no headway since the end of World War II.

U.S. Compared to Other Nations

Although we are making slow progress in increasing our prosperity, as measured during recent years by the amount of goods per person, we still are by long odds the most prosperous people on earth. This can be seen from the following table. It offers a rough measure of how the adjusted output of goods and services per person in the United States compared in 1951 with that in a number of other countries:

COUNTRY	PER PERSON
United States	$1,735
Canada	1,231
United Kingdom	614
France	510

To figure more closely "How Prosperous is the U.S.A.?" we must answer a number of other questions. One of the most important will be the subject of a later editorial in this series. It is "Who Gets What?" How have various income classes and occupational groups shared the total available goods?

Another question that has a basic bearing on the quality and durability of our prosperity is "How fast are we using up irreplaceable natural resources, such as oil, iron ore, and copper, to sustain it?" Any attempt to deal with this very complicated question must also be deferred.

A Problem for the Future

In the meantime, however, key facts about our prosperity are that:

1. Most of the increase in the nation's total production in recent years has been to meet military requirements rather than to improve the American standard of living.

2. The increase in the supply of goods and services actually available for the average American has been slow and halting.

3. We Americans are still extremely well provided with the good material things of life, as compared with peoples in other lands.

These three facts bring to mind a whole series of policy questions. What can be done to speed up progress in improving our prosperity? What—to repeat the question discussed in the previous editorial in this series—can be done to make our prosperity less precarious?

Here, however, the purpose is not to prescribe. It is simply to indicate as accurately as it can be done in a brief article the actual state of the nation's prosperity.

In doing this much, it can properly be remarked that the record presents to the American economy both a problem and an opportunity of surpassing importance. It is that of building a prosperity that will be both more progressive and more secure than any we have known in recent years. In the light of what clearly remains to be done, we shall make a grave mistake if we use up any of our energy in congratulating ourselves on the relatively meager progress here recorded.

McGraw-Hill Publishing Company, Inc.

Fig. 1—Some of the shapes and forms that can be fabricated in a variety of metals and finishes. The multiple plunger machine shown at right is arranged for roll-threading on the screw shell for an electrical lamp socket.

Eyelet Machine Products

versus screw machine products

WALTER E. ALLAN
The American Brass Company

THE EYELET MACHINE, originally designed for making small metal eyelets for shoes, has been modified and adapted for quantity production of small drawn parts in a variety of contours, Fig. 1. Modern machines are capable of handling metal up to 0.05 in. thick, and of drawing shells up to 3 in. deep. Thus, with the current emphasis on less scrap and lower cost production, they are adaptable for production of light, thin-walled sections whenever the quantity required is in the vicinity of 100,000 or more pieces. For substantially smaller quantities, the automatic screw machine may be more economical.

The conventional eyelet machine differs from a transfer press in that it usually has independently actuated plungers rather than a single gate actuated by one or two throws on the crankshaft. This construction, of course, permits greater flexibility in setting the stroke of the plungers. The machine draws the part automatically from coiled strip, advancing the part from station to station by mechanical fingers and holding it until the correct shape is reached. There are no inter-

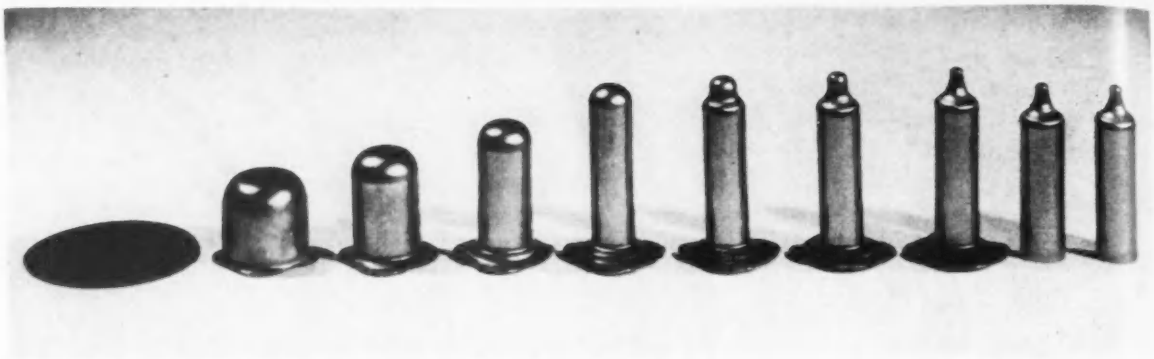


Fig. 2—A typical part made from deep drawing quality Armco iron strip without intermediate anneals. This shows that it is possible to have eight or often as many as ten operations on one part. It is also possible to get more than one operation at each station. The steps listed below give the percentage of reduction of the part at each station of the eyelet machine.

mediate annealing operations, and no special handling of parts for each operation. At the completion of the cycle, the flange is clipped to remove any irregularities produced in the forming operations, and the end is either trimmed or pierced.

The sequence of operations required for the production of the part shown in Fig. 2 is more or less typical:

1. Blank ..... 2 in. dia
2. Cup (50% reduction) . 1 in. dia
3. 1st draw (20% reduction) ..... 0.80 in. dia
4. 2nd draw (20% reduction) ..... 0.64 in. dia
5. 3rd draw (20% reduction) ..... 0.512 in. dia
6. 4th draw (15% reduction) ..... 0.435 in. dia
7. Pierce out bottom
8. Clip flange to size

The sequence indicates that eight, or sometimes ten stations are necessary for some parts. In addition, it is often possible to get more than one operation at one station, as for example, marking the bottom of a part and reducing its diameter at the same time. However, these special applications require wide experience on the part of the fabricator to get a good running job.

Although the part in Fig. 2 is made of deep drawing quality Armco iron, a variety of materials—brass, steel (usually SAE 1010) stainless steel, zinc, copper, bronze, nickel, and aluminum—can be formed. Generally, the greater the ductility of the material, the easier it is to draw, the more work can be put into it, and the less costly are the tools. For example, annealed brass with an average of 65 percent reduction in area is easier to work than a harder brass with a percentage of reduction of only 50 percent. These reduction percentages are reductions in cross-section area when tested samples are stressed in tension to the point of failure, and are not to be confused with the reduction in diameter in the drawing operation. Often a material may have a high percentage of reduction, yet it will be exceedingly abrasive on the tooling, resulting in difficulty of fabrication.

In order to have the strength necessary to resist breakage when the metal is displaced during the forming and drawing operations, a copper base alloy must be free from imperfections such as blisters, and the grain must be fine.

When designing parts for the eyelet machine, it must be remembered that the increase in the length of a shell is a result of reducing the outside diameter without appreciably thinning the wall. Consequently, the operations must be so balanced that the metal will not harden appreciably in the early stages; otherwise, cracking and splitting will occur in the remaining operations.

As a rough guide, the following is a series of flexible rules that may be followed:

1. For most machines, the metal thickness of the part should not exceed 0.035 inch. Length will depend upon the equipment available, but it is usually somewhat less than 3 inches.

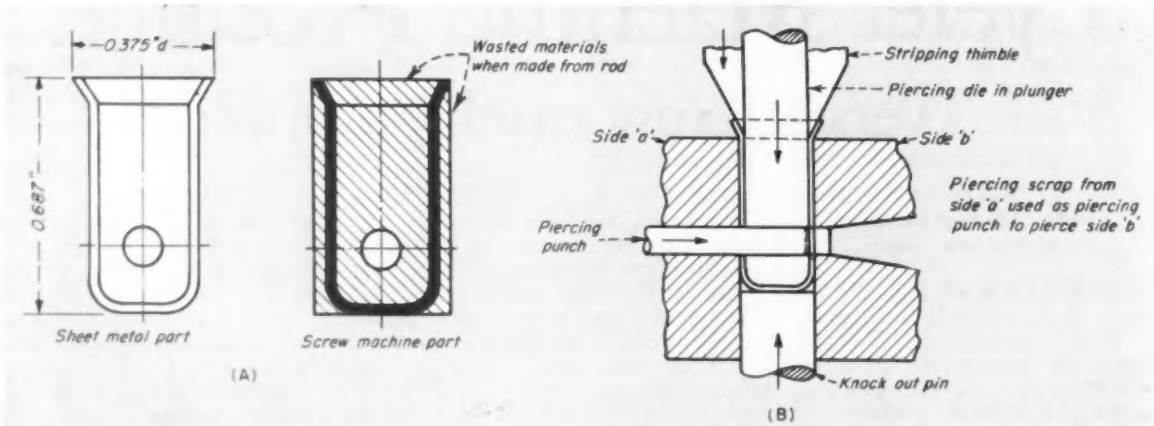


Fig. 5—Switch housing produced as an eyelet machine and screw machine part. In (B) is the tooling used on the eyelet machine.

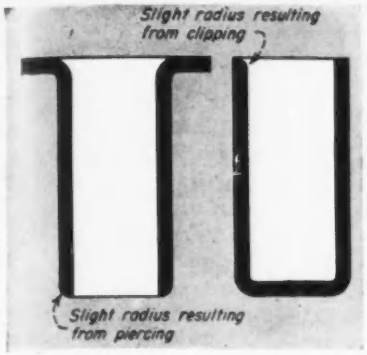


Fig. 3—A slight radius results from piercing the bottom and clipping the part at the end of the cycle, as shown above.

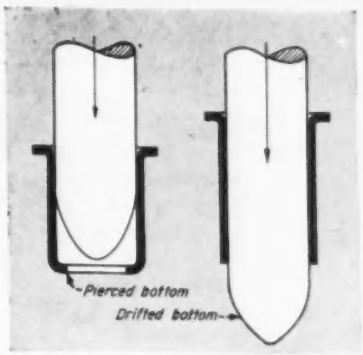


Fig. 4—Either secondary lathe operations or "drifting" can be used to obtain square edges in a part with a pierced bottom.

2. Tolerance on the drawn diameter should be ± 0.002 in. or greater where possible, although ± 0.001 in. has been held on occasion. Commercial tolerances on length are on the order of ± 0.005 inch.

3. Variations of sidewall thickness as well as thinning of the sidewall should be avoided.

5. The "clipped trim" edge is not absolutely square with the axis of the part, but is square enough for most practical purposes. Should a dead sharp edge be required, an additional trimming operation will be necessary. Often the slight radius resulting from the clip trim is a definite advantage if a part is to be inserted into the drawn shell, because it gives a slight centering action that often speeds assembly.

6. A pierced bottom produced by punching out the excess metal results in a slightly rounded outside corner, as in Fig. 3. Square edges can be produced by means of a secondary lathe trimming operation, but this is an additional expense that is seldom required. As with the clipped edge, the slight radius can be a definite advantage if the part is to be assembled to another part.

A slight improvement on the pierced edge from a standpoint of squareness is often obtained by piercing the part slightly smaller and shorter than desired. The part is then submitted to a further operation called drifting, where the part is sized by a bullet-nosed punch. Detail of this operation is shown in Fig. 4. This type of hole required one additional plunger as compared with the pierced bottom, and is often not possible as all of the plungers may be required to complete the part.

The parts shown in Figs. 5 and 6 are typical of the type of product that is best suited for eyelet machine fabrication.

The screw machine part Fig. 5(A), was being used as a switch. The holes were drilled in a secondary operation. By moving the holes slightly away from the closed end to get die strength, the two holes were pierced at one time with one punch. The scrap from the first hole was used as a punch to pierce out the second hole. The tooling required for this operation is shown in Fig. 5(B). The gross weight of material required is 4.43 lb per thousand pieces as compared with approximately 25.5 lb per thousand pieces when made on an automatic screw machine. Production is in the order of 4,000 pieces per hour.

The piece in Fig. 6(A) was part of a cigarette lighter. The redesigned part required a gross weight of material of 1.44 lb per thousand pieces, as compared with the 19.1 lb per thousand pieces when made on an automatic screw machine. Production is in the order of 3,500 pieces per hour.

The radio tube contact pin (B) originally made as a screw machine part, is now being made in a variety of sizes at a higher production rate. The deep hole drilling is eliminated, and the open end can be more easily flared at assembly when made from strip stock. The gross weight of material required is 2.88 lb per thousand pieces, as compared with 8.7 lb per thousand when made on an automatic screw machine. Production is about 4,500 pieces per hour.

In (C) the bulb housing on a flashlight was designed so that all operations, including threading and marking, could be done completely on the eyelet machine. The problem here was incorporating the threading into the tooling so that it, too, could be made automatically on the same machine that made the part. The gross weight of the material required was 5.61 lb per thousand pieces as compared with 42.6 lb per thousand pieces when made on an automatic screw machine. Production was at the rate of 3,000 pieces per hour.

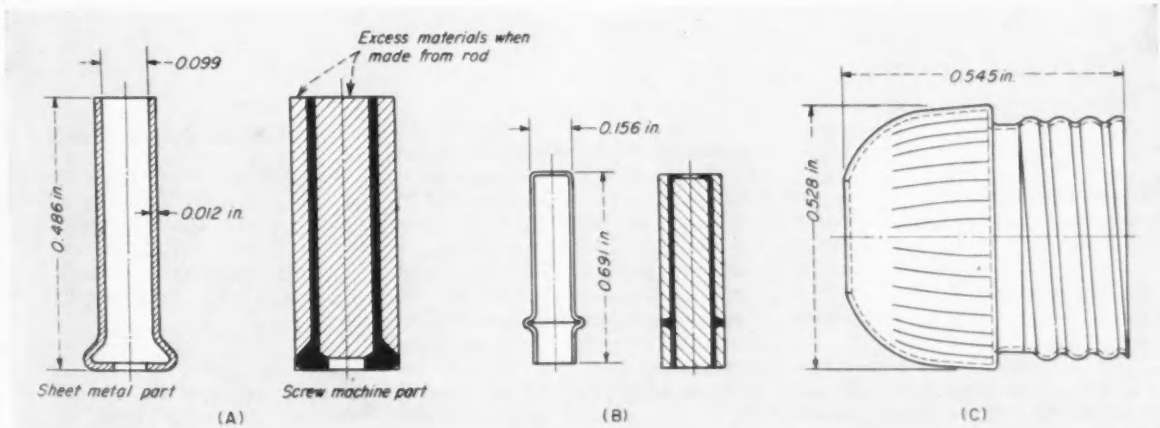


Fig. 6—Typical eyelet machine parts: (A) cigarette lighter piece; (B) radio tube contact piece; (C) flashlight bulb housing.

Table I—Typical Applications for Multi-Contact Connectors

- Radio transmitters
- Amplifiers
- Portable power packs
- Television cameras
- Micro-wave relays
- Aircraft instrument panels
- VHF communication equipment
- Starting equipment for aircraft
- Sub-assembly connections
- Servomechanisms
- Sound systems
- Electric motors
- Public address systems
- Transcribing equipment
- Telephone connectors
- Oilfield engine starters
- Geophysical instruments
- Voltage regulators
- Position indicators
- Transducers
- Cameras
- Projection equipment
- Potentiometers
- Geiger-Muller counters
- Electronic tuning equipment
- Accelerometers
- Electrometers
- Glideslope receivers
- Code selectors
- Pyrometers
- Oscillographs
- Strain gages
- Mass spectrometers
- Computing machines

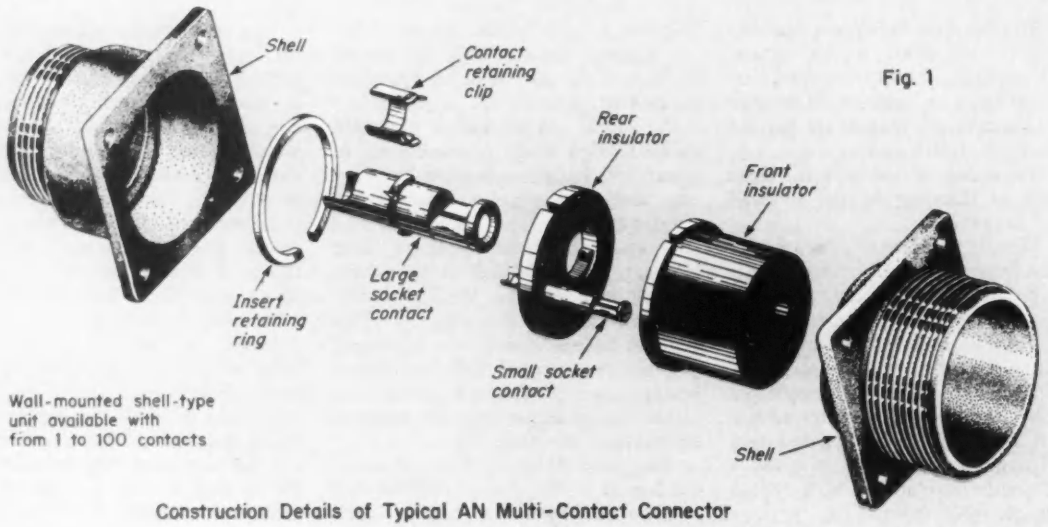


Fig. 1

Construction Details of Typical AN Multi-Contact Connector

Multi-Contact Electrical

LESLIE BAIRD
Cannon Electric Company

THE MULTI-CONTACT electrical connector is a precision device that permits quick connect and disconnect of from 2 to 40 or 50 and frequently up to 100 or even 200 circuits. As such, it is widely used in all types of electrical and electronic gear, Table I.

The variety of sizes and classes available is extremely wide and depends on the requirements of the application. In general, four major factors govern the specification, Table II. This list gives merely skeleton requirements to which connectors can be adapted, however. Each characteristic fans out into detail that must be taken into consideration in matching the connector to the application for proper operation over the full life of the unit. Standard fittings may be used for the majority of such requirements, but minor as well as major modifications must often be made before a suitable connector is produced. These may involve anything from modifications in finish to special shell constructions.

Standard Types

Basically, a connector is a receptacle and plug assembly consisting of a shell, insulator, contacts, and various associated parts and accessories, Fig. 1. General engineering data on these components can be summarized as follows:

Shells. Early small-quantity, production shells were sand cast or machined from bar stock. Special runs today are frequently made in that manner, but die casting with multiple cavity molds results in higher produc-

Table II—Factors Governing Specifications

ELECTRICAL	MECHANICAL	FUNCTIONAL	SPECIAL
Amperage	Weight	Temperature	Military specifications
Voltage	Shape	Vibration	High voltage
Shielding requirements	Space availability	Moisture	High altitude
Current frequency	Method of cable or conduit entry	Appearance	Waterproof or watertight
Number of connections	Coupling means	Explosion proofing	Miniaturized or sub-miniaturized
Material for inserts, contacts and insulators	Finish	Pressure sealing	Oil and acid resistance
Permissible voltage drop across contacts	Method of assembly	Fireproofing or flame barrier	Fungus resistant
	Type of usage		Combination pneumatic-electrical connection

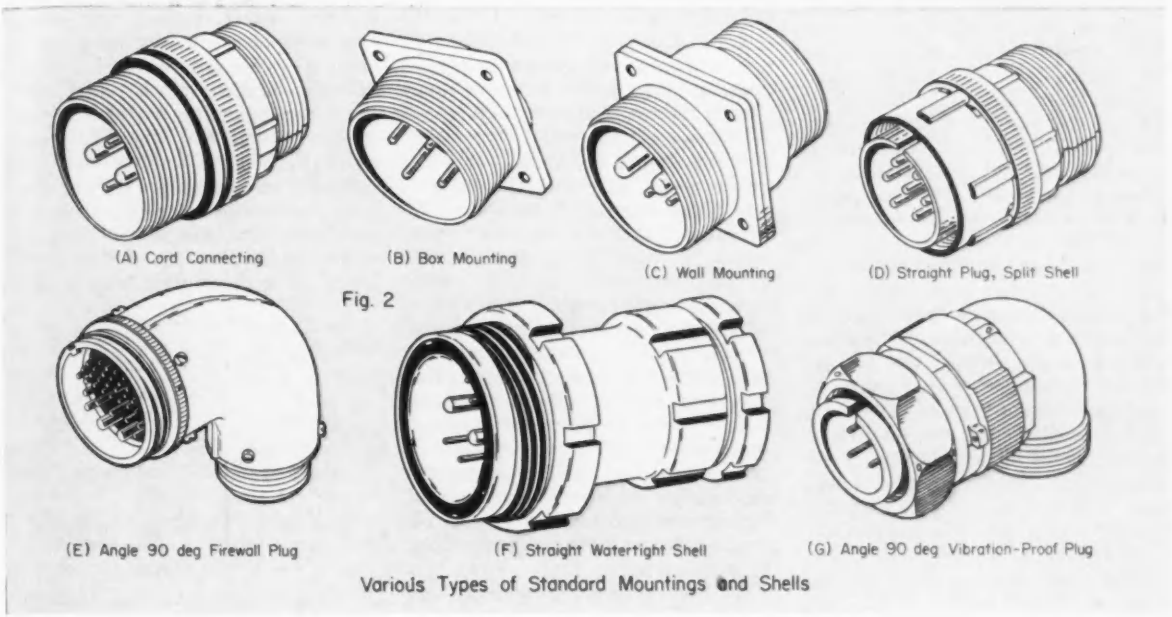

(A) Cord Connecting
(B) Box Mounting
(C) Wall Mounting
(D) Straight Plug, Split Shell
(E) Angle 90 deg Firewall Plug
(F) Straight Watertight Shell
(G) Angle 90 deg Vibration-Proof Plug

Fig. 2

Various Types of Standard Mountings and Shells

Connectors

Types Characteristics Applications How to Specify

tion and lower cost. However, other processes also are used.

Shells are made of zinc, aluminum, brass, rubber, and steel, with a wide variety of finishes. The materials are chosen for strength requirements and —since the majority of connector developments have been made in equipment to be used on airborne craft— for light weight. Plug shell types fall into two classifications: straight or 90 deg angle, Fig 2. The 45 deg types formerly used in aircraft are now generally obsolete, but conduit fittings in 45 deg angles are available.

In receptacle shells, wall and junction box mountings are commonly used. The box mounting receptacle unit may be made into a wall or bulkhead feed-through unit by the addition of a junction shell. Either split shells or "solid" shells may be specified, the former being split horizontally or vertically to the connector axis to facilitate wire inspection and assembly.

To effect a moisture or weatherproof shell, certain differences in construction and parts are made. In the AN- "M" types discussed later, resilient inserts, grommets over the solder pot terminals, and telescoping rubber bushings that seal the cable clamp entries are provided. In watertight brass shells, a heavy Acme thread and special sealing ring are combined to produce a fitting capable of withstanding 250 psi pressure.

Coupling Means. Various means are available for coupling the two halves of a connector. The strongest coupling is the threaded coupling nut which, when tightened, engages the pin and socket contracts by a screw-jack action. When tightened, coup-

Table III—Current Ratings of AN Type Contacts

Contact Size	Current, Amp	Potential Drop, Millivolt (Max.)
16	20	21
12	35	20
8	60	12
4	110	10
0	200	10

Table IV—Operating Voltages of Typical AN Type Connectors

Service	Limit Operating Voltages At Sea Level		Effective Creepage Distance (Nominal)	Mechanical Spacing (Nominal)
	DC	AC (RMS)	Inch	Inch
INST	70	50	1/16	
A	200	150	1/8	1/16
D	500	275	1/4	1/8
E	650	350	5/16	1/16
B	750	500	5/16	1/4
C	3,000	2,100	1	5/16

Connectors rated for INST (Instrument) service are normally intended for low voltages and currents.

ling nuts are ordinarily provided with lugs or holes through which to string wire for "safety wiring," this holding the two parts together to prevent the nut from vibrating loose. However, other connectors such as audio types do not require these vibration proof features but, instead, are designed with a latch lock for quick thumb pressure connection or disconnection. Other types have neither locking nor latching feature but are held together by friction. Still another has a bail and gear method of coupling for use in crowded installations. The master engine disconnect used for the engine circuits of Constellations has a similar cam type engagement with a nut that is turned by a wrench or pliers.

The spring-loaded butt-type contact is a late development in the field of connectors but it is limited to a few specific shell styles, none of them among the *AN* specifications. Primarily, the spring-load construction is used in fittings with a large complement of contacts such as those made for guided missiles, where the plug disengages automatically from its receptable. Another modification of this contact is employed with a special connector having 500 contacts in one unit. Ordinarily five hundred standard pin and socket contacts would require an extraordinary force to disengage in one unit and would also need various guide pins to keep the two parts of the complete connector from engaging or disengaging unevenly, thus risking damage to the pins as well as to the insulator material. Another newer use of the spring load type of contact is in a small plug series designed especially for the US Army Signal Corp Audio Equipment. With this type, engagement is effected by a 25 deg rotation of the plug with a bayonet *"J"* slot.

Insulators. Formerly fabricated of a phenolic compound, insulators were made in several parts. Today, almost all insulators are molded in a single piece to simplify the manufacturing process and reduce the overall dimensions and weight. High dielectric strength is one of the prime requirements, and for that reason, the insulator is usually made of a synthetic polychloroprene rubber. However, ceramic and transite insulators are used for high temperature applications, and other materials can be specified to meet special conditions.

Contacts. Brass and bronze contacts are widely used, but the high copper alloys such as beryllium, provide better conductivity and are preferred, especially in the larger sizes because of their spring qualities.

The pin contact is usually a solid prong, rounded at the end, with a holding shoulder and a tinned solder pot, Fig. 3. This tinned solder pot is used for all but a few connectors, the exceptions being crimp-type contacts used in the maximum heat resistant connectors designed for aircraft engine firewalls and for thermocouples. Good design necessitates that the solder pot not accommodate a wire of greater current-carrying capacity than the contact itself.

Full-floating socket contacts, i.e. both ends subject to a nominal "tilting" within the insulator, assure good engagement without undue strain on the insulator. Napkin ring type contacts and split types also are used, but it is usually important that the circumference of the pin seat securely in the socket to keep the millivolt drop at a minimum. For best performance, both the pin and socket contacts should be milled.

Current carrying capacities of contacts in the AN series are given in Table III. Voltage ratings are governed to some extent by operating conditions; for example, reduced flashover ratings at high altitudes for airborne equipment are based on conservative safety factors, while the same equipment used at sea level or lower altitudes can be rated at substantially higher values. Table IV gives the operating voltage at sea level of typical AN type connectors, and Table V gives flashover voltages.

Guided missile breakway type connectors constitute one of the most extraordinary developments in the connector field. They are distinguished first of all by their spring-loaded, butt-

Table V—Flashover Voltage Ratings of Typical AN Connectors

Service	Test Voltage 60 Cycle (AC)
INST	1,400 (Peak)
A	2,800 "
D	4,000 "
E	5,000 "
B	6,500 "
C	10,000 "

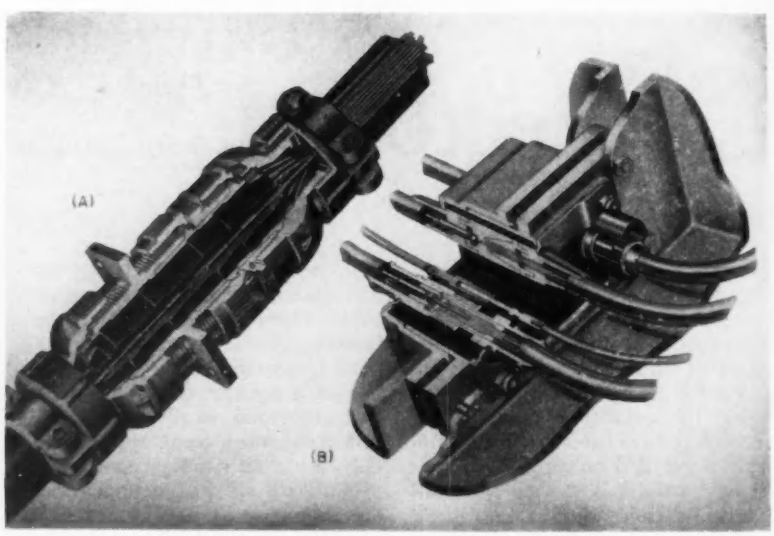


Fig 3—Cutaways of pin and socket arrangement for: (A) special purpose AN-M type connector; and (B) rack type connector having standard and coaxial contacts. Soldered connections are used for most assemblies, but crimp type contacts are necessary in high temperature applications such as aircraft firewalls.

type contacts, eliminating the problems of separating force with regard to contacts. Because these connectors are used for automatic breakway applications, they have solenoid, manual, lanyard, or drop-away release or ejection mechanisms. Standard spring-loaded, coaxial, and thermocouple contacts are used in their various insulators. The majority of the types carry from 40 to 60 contacts, and have various types and angles of cable entries, while some have receptacles made for the curvatures of the missile.

Connectors for Specific Service Requirements

The greatest volume of connectors since the rearmament program began prior to the outbreak of World War II has been in the Air Force-Navy (AN or MIL) types. Although the AN lines are usually attractive price-wise to the commercial user, they are not always adaptable to the hard usage and rugged conditions of commercial requirements. An example is the thread—NEF—which cannot compare in strength to the heavy Acme threads of other non-military types.

Audio types of connectors, having a maximum of 30-amp contacts with a minimum flashover value of 1,100 to 3,400 volts were designed originally for low-level sound circuits but have been adapted to many other commercial applications. Newer designs within these types are provided with weatherproof and moisture-resistant features which also extend their use to new applications. However, connectors in this series are relegated to units having a limited number of contacts.

Higher amperage power connectors run from 250 to 1,500-amps, although the latter is limited to the largest ever built—a connector for the Boeing Stratocruiser passenger plane.

AO connectors, designed especially for the US Army Ordnance, are made for the extreme outdoor conditions encountered by tanks, trucks and military vehicles. Their closest parallel is the *AN* line whose contact arrangements (layouts) they follow.

For heavy duty requirements where a true waterproof seal is required and where connectors may be used underwater or in extreme moisture conditions, a rugged, simple series is available based on *AN* shell sizes #15, #22, and #36. Thus contact arrangements are available from the large selection of *AN* inserts in these sizes and use is limited only to the required cable entry maximum diameters. Wires must be molded in the clamp gland for perfect sealing. A heavy Acme thread and special packing rings together with brass shells combine to produce a suitable connector for difficult, rugged applications.

Miniaturization has come in for much attention within the last year. Small sizes in the *AN* and *K* lines are, in a sense, miniatures though limited in variety. The small *AN* sizes from 8S to 14S have inserts of $\frac{3}{4}$ to $\frac{1}{2}$ in., with an overall length in straight plug shells from 1 17/16 to 1 31/32 in. Inserts in the small sizes of the line start with a $\frac{5}{8}$ in. dia. and increase to $\frac{7}{8}$ in. in the next larger size, with overall lengths 2 1/32 in. in the same sizes. The number of contacts accommodated in these sizes in the *AN* line range from one to six, mostly #16 rated at 20 amperes. In the small sizes, the range is 1 to 12 contacts in the small sizes, with #16 and #10 contacts rated at 10 amps and 30 amps, respectively. But although small, these are not true miniatures.

In the sub-miniature line, new shell and insulator materials are used, making possible an extremely small construction Fig 4 (A). The smallest of this series has fifteen 5 amp contacts, with flashover ratings of 1,000 v to 1,500 v rms, depending on the vinyl tubing used over the solder pots ends of the wires. This little fitting is only 1 17/32 in. long, 31/64 in. wide and 27/64 in. deep, plus a 9/64 in. solder pot extension. These types are for rack and panel mounting but, with the addition of a junction shell with an integral clamp, can be used as plugs. Insulators are Nylon FN-10001, and the shells are steel. The finish is cadmium plate with a chromate conversion finish.

Other slightly larger fittings with 25, 37, and 50 similar contacts are now in production not only to meet the demand for a truly small connector but also one with strength, stability and high current capacity.

Undoubtedly more minatures and sub-miniature types will be built in the future to keep pace with the redesign of equipment to smaller and smaller dimensions. Nevertheless, greater skill and lower wattage irons are required to solder the miniature connector, a factor apt to be overlooked. Many applications, of course, do not require these small dimensions.

Another series long in use is the laboratory and switchboard group used mainly as switching plugs for test equipment and experimental laboratories and switchboards in industrial plants and educational institutions. These include single, two, four and six contact fittings, 75 amperes. Associated in general application and construction is the tandem type connector, having a single pin plug. The two socket contacts of the mating receptacle are in tandem and are engaged one after the other by the plug. This type was built for electric analog computers and also adapted for a-c network analyzers.

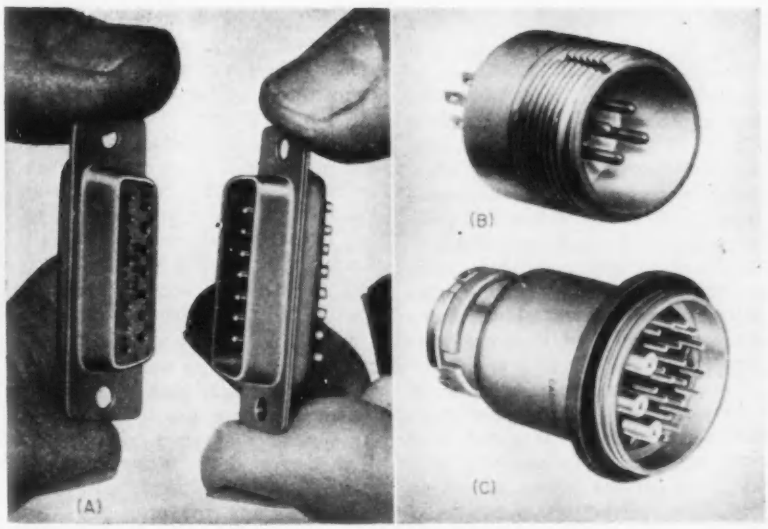


Fig 4—Connectors for special service: **(A)** 15 contact sub-miniature connector with formed steel shell, nylon insulators, and gold plated contacts; **(B)** hermetically sealed connector with vitreous fused insulating element and steel shell and pins; **(C)** television camera connector having three coaxial contacts plus standard contacts.

CONNECTOR REQUIREMENT INFORMATION

1. Connector, Type—Wall mounting, box mounting, straight cord, or 90° cord _____

2. Dimensional Restrictions (outside diameter, overall length, etc.) _____

3. Cable Outlet, size & type _____

   Cable, Fastening Means of (ferrule & nut, or clamp) _____

4. Shell, Material and Finish of _____

5. Contacts, Pin or Socket _____

   Number & Size of Wires to be accommodated _____

   Amperage _____

   Voltage _____

6. Extent to which connector must be weatherproofed _____

7. Quantity Involved _____

8. Additional Requirements _____

9. Submit sketch of item with all information available, if possible _____

10. Where fitting will be used: _____

11. DATE design required _____

Selection of Multi-Contact Connectors

The number of conductors, and their amperage and voltage rating, constitute a basis for connector selection, but moisture conditions or the need for a degree of pressurization, may limit the variety available. Then the mounting space or area may be so small as to rule out a fitting otherwise adaptable. Thus, a careful analysis of equipment characteristics and operating conditions will allow the manufacturer to provide guidance toward the selection of the proper connector. Too often, incomplete information is given to connector engineers, frequently resulting in delay and sometimes necessitating equipment redesign.

Beginning with temperature as the overall operating condition, *AN* standards require a connector to function satisfactorily at a +185 F to −67 F. While connectors may operate without trouble at higher or lower temperatures, insulators of melamine do not function as well as the resilient materials beyond these limits.

To meet extreme conditions of heat, for instance, a vitreous fused contact insulation in a steel sheel will function at +400 F and in emergencies up to 1,000 F.

Connectors made for firewalls of aircraft engines, are equipped with steel shells, transite insulators and crimp type contact terminals to provide flame barriers in case of engine fires. They will keep vital circuits in operation for five minutes at 2,000 F. The commercial use of these connectors in other applications has not been determined.

Inserts molded of resilient material have proved successful in combating moisture accumulations from rapid altitude changes, and, with the resilient material grommets over the terminals and telescoping bushings of similar material, combine to produce a good moisture seal. These are found largely in the new *AO* ordnance connectors and the special purpose *AN-M* Series. However, weatherproofing is also effected by the use of rubber bushings, special sealing rings within the coupling nuts and also by sealing means at points where moisture might penetrate the interior of the shell.

Appearance. Where connectors are used and must be dressed up for the public to some extent, such as for microphones, bright finishes are desirable. Here, bright nickel or satin chrome finishes are available.

Pressure sealing. Pressure-sealing, like moisture, involves various degrees. Pressurized *AN* and *K* receptacles having pin contacts have been in use for some time and have been used in high flying commercial as well as military aircraft. Similar pressure seals are available in the resilient insert group where the socket inserts may be used. One type, for instance, meets the minimum leakage of 5×10^{7} cc per sec. at room temperature. Other sealed requirements require no leakage of air or pressurized gas (containing not less than 10 percent helium by volume) in excess of 1 micron cu. ft. per hr at a differential pressure of approximately one atmosphere. The hermetically sealed types with vitreous type insulation creates a seal capable of meeting such requirements.

Various special requirements are already covered by special purpose connectors. Military specifications include a wide variety of special *AN* connectors not necessarily carrying *AN*-nomenclatures. High voltage types include connectors with extensive insulation or wide creepage paths, or connectors have Teflon insulators. Fungus resistance proved to be a saving factor in equipment used in the South Pacific during World War II, and in this case special finish and coating of the insulators is required.

Several connectors have been made carrying air lines as well as electrical circuits in the same fitting. Connectors for air only have also been produced for a number of years, although the demand for these fittings is quite limited.

In specifying any connector, complete information should be made available; the chart at the top of the page will serve as an excellent guide toward this end.

Type Drive	Regulation, percent	Speed Range	Horsepower
All Electronic Tube	2-4 ½ with tachometer	100:1	1/70-30
Eddy Current Clutch	2-4	17:1	1-4,000
Ward Leonard Electronic Control	2	50:1	15-200 Larger by cascading
Ward Leonard Magnetic Amplifier	5 of set speed	8:1 Cont. torque 16:1 Cont. hp	5-150 Larger by cascading
Ward Leonard Rotating Regulator	2-3 Standard ½-1 Special	120:1	1-4,000 and larger

How Adjustable Speed Electronic Drives Compare

- General types of semi-automatic and automatic speed regulators.
- Design and performance of commercial units.
- Applications to which they are best adopted.

T. R. BREUNICH
Project Engineer
Sonntag Scientific Corporation

ADJUSTABLE SPEED DRIVES today are at an unanticipated level of refinement because of demands for better speed control, speed regulation, and synchronization of components. Future requirements will undoubtedly be even more stringent as automaticity of operation is further applied to industrial machines and military equipment, and will be met in many instances with packaged drives featuring a-c power input, d-c drive motors or clutches, and low powered electronic controls to give close regulation over a wide speed range.

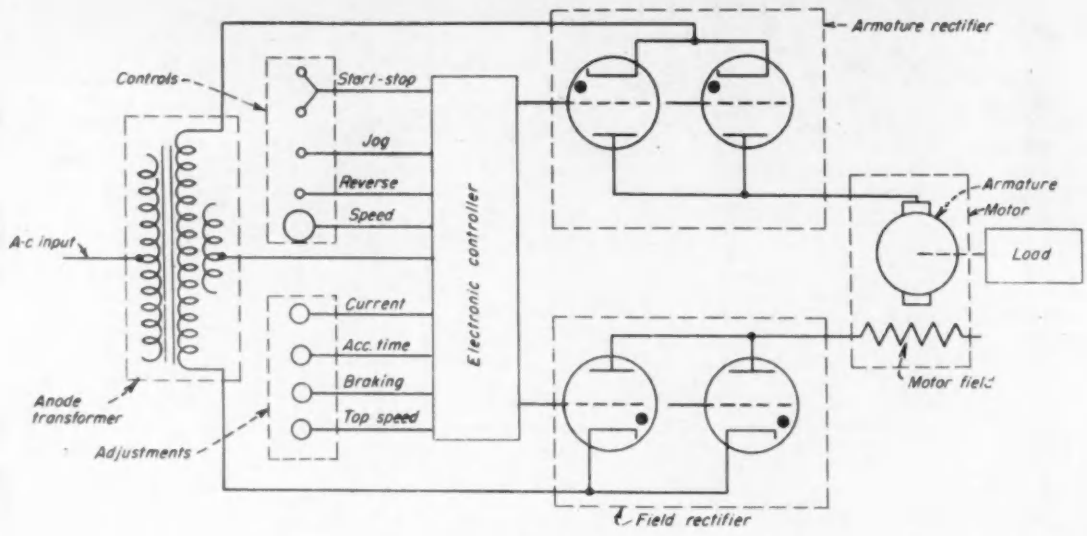
While these drives all use standard a-c power and some form of d-c drive, the wide speed range, regulation and ease of control cannot be realized with a primary d-c source. This is due to the need for a variable voltage supply. The only efficient way to achieve this is to regulate the supply at its source. Hence, the use of motor-generator sets in Ward Leonard systems or electronic tubes acting as variable voltage regulators.

Many methods are employed to achieve the end result in electronic drive (see table above). The question of cost, sensitivity, speed range, power, and principle of operation all influence the design. It is obvious that a speed range of 100 to 1 with 1.0 percent regulation is more costly than a unit with a 4 to 1 range and 5 percent regulation. In like manner the former requires different components and provisions to give the required results. The design of the different drives reflect this and consist of units that can give the desired results at the lowest cost: 1. All electronic drives using vacuum and gaseous tubes throughout and controlling both armature and field voltage. 2. Eddy current clutches using low wattage coils in the clutch to control slip, and vacuum tubes or magnetic amplifiers control elements. 3. Ward Leonard systems using motor-generator sets for the main power source and controlling the drive motor voltage by varying the field of the generator. Such field control is obtained by means of electronic tubes, magnetic amplifiers, or special forcing generators.

All Electronic Drives

This type of speed control utilizes vacuum tubes for the control circuit and grid controlled gaseous discharge tubes for the power circuit, Fig. 1. A multi-winding transformer is used to transform the a-c power to the various voltages needed. The power circuit, consisting of thyratron tubes, is fed from a high voltage winding of the power transformer. The anode connection of these tubes goes through a current transformer so that a signal is available for the control circuit.

The full wave rectified power is fed



General Electric Co.

Fig. 1—Schematic diagram of adjustable speed control utilizing electronic tubes for both the power and the control circuits. Current and voltage feedback are used to control the rectifiers and to maintain a fixed voltage across armature terminals.

directly to the motor armature. The rectifier tubes act as modulating d-c voltage valves, with current and voltage feedback to control setting or flow through the valves. Usually, both current and voltage feedback are necessary to provide stability and give close regulation. Current feedback is used to limit the current of the motor to safe limits and also to provide compensation for the IR drop in the armature as the power increases. Voltage feedback is used to maintain a fixed voltage across the armature terminals for any given setting of the speed control. This voltage is adjusted by the current signal to give the noted IR compensation.

The armature voltage is adjusted until it nulls the control circuit reference voltage, Fig. 2. This reference is selected by the speed control potentiometer and has a fixed value for every speed setting. Whenever the two voltages differ, the error signal is used to re-balance them. The current signal acts to decrease the amplification of the voltage signal and so the voltage has to build up before null conditions can be established. This is called IR drop compensation and reduces the speed droop due to the IR voltage drop in the armature.

Current feedback is also used to limit the power flow through the tubes and motor. When the current flow increases above normal the control amplifier acts to reduce the armature voltage and so limit this current to a maximum set value. With this control the system is not a constant voltage but a constant current drive, and the speed is not closely regulated. These drives can be stalled without damage, and their acceleration is controlled.

When close speed regulation is desired, tachometer voltage feedback is used instead of armature feedback. This gives a signal that is a pure speed signal and not one that is affected by the motor characteristics.

The heart of all these drives is the operator that links the control section to the power section. This is the element that takes a few watts of control signal and transforms it into kilowatts of controlled power. The electronic drives use two basic systems for this, one being grid phase shift and the other grid d-c bias shift, Fig. 3. In the phase shift control a saturable reactor is used in a phase shifting circuit. This saturable reactor, also called a magnetic amplifier, has an a-c and d-c winding, the latter of which controls the magnetic saturation of the core. At a low current levels the core is unsaturated and the a-c winding very reactive. At high d-c current levels the core is saturated and the a-c winding is purely resistive. This inductive change has the affect of shifting the phase of the a-c voltage, and is applied to the grids of the thyratron tubes to control their firing point and voltage output.

The grid bias system uses constant phase a-c voltage. By changing the d-c level of this voltage with respect to the tube cathode and applying it to the grid, the point at which it reaches the critical firing point of the grid can be shifted. This shift is similar to the phase shift in that the time the tube conducts is controlled and so its voltage output. The main power is obtained from the armature thyratrons using grid control to adjust the voltage to the desired point, and the current feedback to control maximum flow in the circuit.

The all electronic drive has been extensively used on machine tools to automatically give constant cutting speeds at varying diameters, to synchronize two different feeds on one tool, and to supply wide speed range drives.

One application is on a milling machine where the drive is on the feed screw and acts to maintain a preset tool load. The transducer is a current transformer in the leads of the spindle motor; its signal is proportional to the load or torque on this motor. As the torque is caused by the cutting tool, the signal is an indication of the cutting force, and is used to control the feed and keep the torque constant. The machine was used to cut fins on aircraft cylinders and by increasing the feed in non-cutting areas and increasing tool life by load control, the use factor of the machine was increased by 30 percent.

This method may also be adapted to multi-spindle milling machines where the signals of all the spindle motors are used and the feed regulated to maintain the preset load on the maximum loaded spindle.

One of these drives is used on a lathe cutting a spiral on a flat plate. The nature of the groove limits each pass to a shallow cut. The drive is arranged to increase the spindle speed as

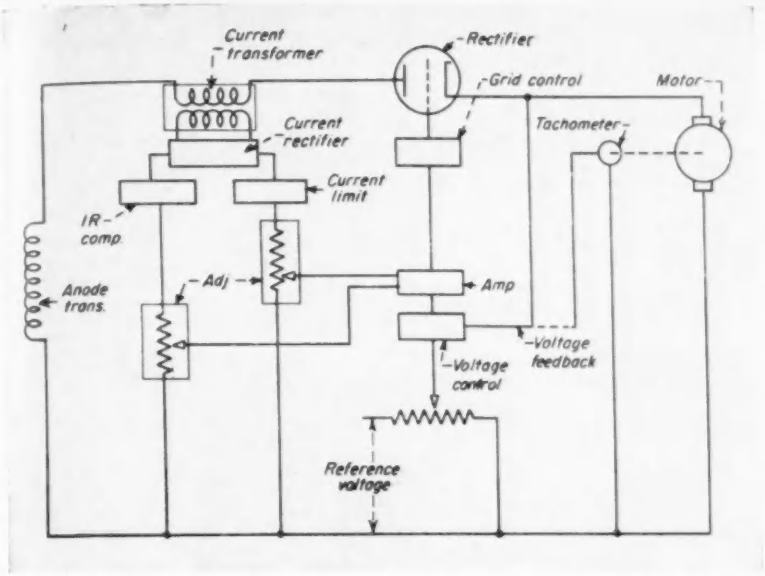


Fig. 2—Using manual operation, a speed control potentiometer is used to regulate the reference voltage, against which the control voltage is nulled. Note tachometer feedback.

the tool moves toward the center by having the tool holder operate a potentiometer. At the end of the cut, the spindle is reversed and its speed increased by switching in a preset speed potentiometer. The current limit feature of the drive keeps the motor from overloading and provides smooth deceleration and acceleration. Compared with a 3 to 1 ratio two-speed drive, production was increased 48 percent and the cost was only 10 percent more.

These drives are also widely used to control strip speed of tension in winding applications.

One drive developed for this maintains a constant strip speed but does not control tension. The transducer is a tachometer generator driven by an idler roll in the system. This is a form of tachometer feedback and the control acts to keep the tachometer voltage a constant by slowing down the drive motor as the reel builds up. Current limit and anti-hunt circuits control the acceleration of the drive and keep it operating smoothly. An important feature of this drive is that many base winding speeds can be selected and automatically maintained.

A similar drive uses both speed and torque control. The current limit is controlled by the diameter of the reel and increases as the reel builds up. This torque build up need not be linear as it will follow the winding characteristic of the variable resistor.

The problem of synchronizing a machine and a conveyor or two machines is accomplished by the use of movable core reactors and photo cell controls. These systems use a loop of material to support the reactor armature or obscure a light beam. As the loop changes due to lack of synchronization, the control signal changes and the speed of one drive is altered to correct the condition. The extreme of this is a system that uses selsyns as the transducers and two drives. One drive is the master or independent drive while the other is the slave or follower. The synchro signal is used to keep the two not only in synchronization but also in close phase relationship.

A more common application of this principle is the tachometer follower system where one drive tach feedback is compared with that of a second drive and as the first changes speed the differential signal is used to make the second follow; this is not absolute synchronization as noted above. Another variation is ratio control where the change in tach signal gives a percentage control of speed in the second drive rather than a 100 percent control.

The process industries use them for pumps where ratios of different materials must be maintained, the control in this case being a temperature type controller recorder.

There are many other standard uses such as wire drawing mills, conveyor controls, bakery oven drives, drafting room printing machine drives and machine controls where only their wide speed range, ease of control and good regulation are desired.

They are also invaluable on test stands where the performance of pumps, fans and bearings is to be checked. Several static tension-compression testing machines use these drives to operate the power loading screws that move the testing heads. The wide speed range gives finger tip control of testing speeds or rate of strain loading, and the close regulation maintains this as load increases.

In the dynamic testing field, or fatigue testing, these drives are used to power oscillators, which test struc-

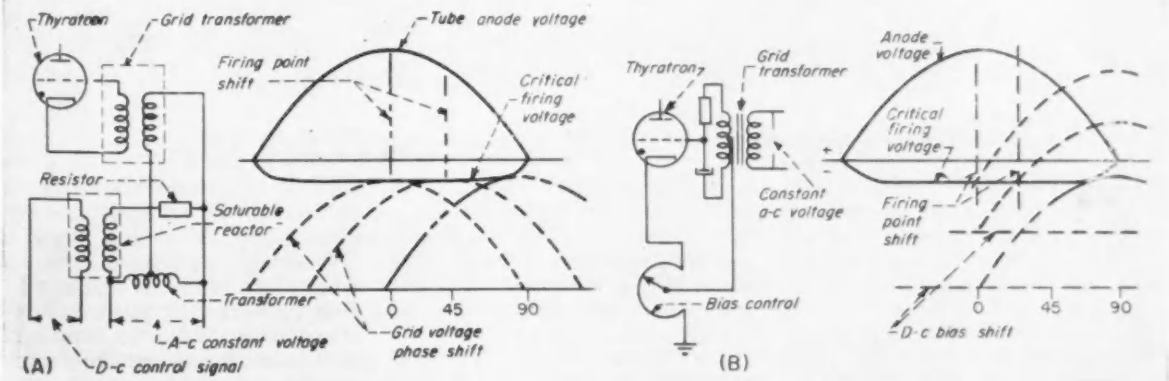


Fig. 3—In the electronic drive, either grid phase shift (A) or grid bias shift (B) controls the firing point of the thyratron tubes.

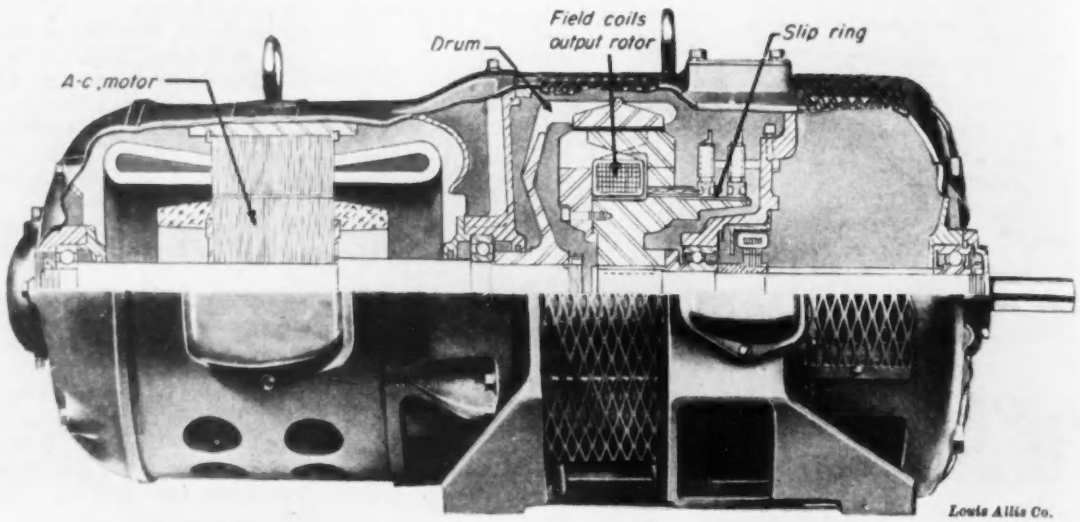


Fig. 4—An eddy current clutch can be used to regulate the power output in response to a low level signal input, thus performing the same function as phase or bias shift for thyratron control.

Fig. 5—With manual instead of automatic current (constant torque) or voltage (constant hp) feedback control, the torque of an eddy current clutch drive will follow these curves.

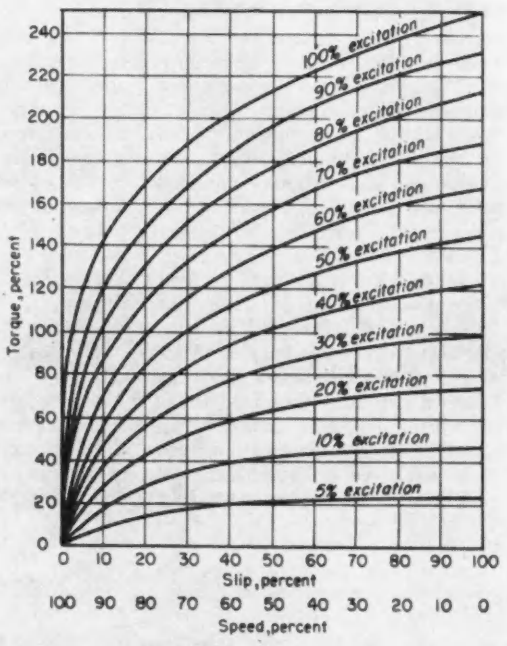
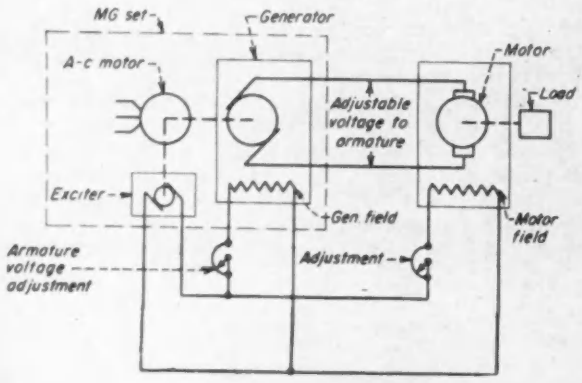


Fig. 6—Typical Ward Leonard system using rotating generators for the power section and tube or magnetic amplifier controls to regulate the generator field.



tures for resonance points and strength under vibration. In this application a wide speed range is necessary, for a test of a ship structure requires speeds of from 400 to 1,800 rpm while aircraft structures require 1,600 to 7,200 rpm. Besides this speed range, regulation is important for when a structure goes into resonance, the energy absorbtion goes up. Unless the drive holds its speed, the phenomena cannot be studied.

Eddy Current Clutch Drives

The second type of drive uses an eddy current clutch as the operator or connector between the control sections and the power section. This system, shown in Fig. 4, consists of an a-c drive motor, eddy current clutch, and control section.

The clutch performs the same function as the phase and bias shift controls on the thyratron drive. It takes the low level signals of the control section and controls the main power output. This clutch consists of a wound rotor on the output shaft and a cast drum on the motor shaft. The drum rim covers the pole faces of the wound rotor. When the rotor is excited by d-c current, the drum rotates and the magnetic field that is set-up causes eddy currents to flow in the case

drum. Torque, Fig. 5, is a function of field strength and slip.

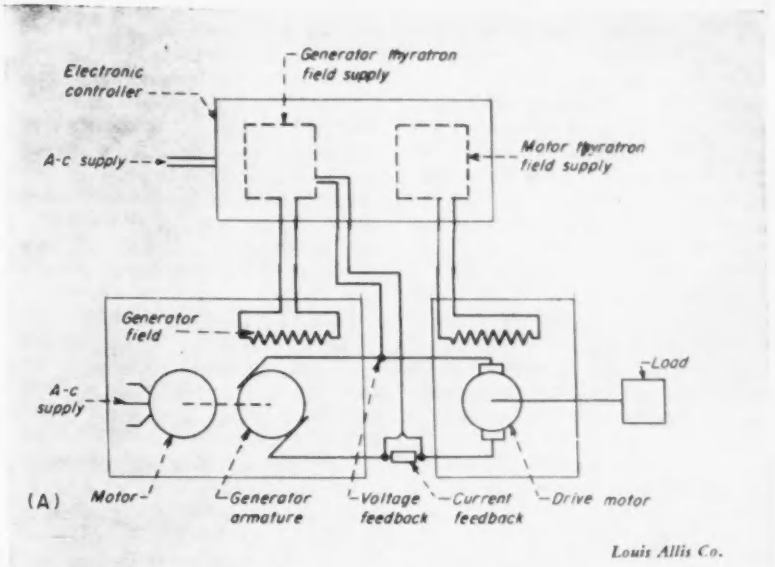
The control section adjusts this field voltage and, as in the first type of drive, a reference voltage or speed is selected by a potentiometer control, and a feedback voltage from a tachometer on the output shaft is nulled against it. The control section adjusts the excitation of the clutch winding and also its slip, until the output speed matches the selected speed.

The control of this drive can be varied to achieve different characteristics. The use of current rather than voltage feedback gives a constant torque condition. A combination of current and voltage feedback gives controlled torque and close speed regulation. If both feedbacks are eliminated and the excitation controlled manually, the torque will follow the curves of Fig. 5.

The eddy current clutch drive has again many of the same applications as the previous type. However, the speed range is limited to 6:1 on a continuous basis. Where large speed ranges are necessary, multi-speed motors must be used. This gives two to four major motor speeds added to the clutch range of 6:1 and so the higher ranges are achieved.

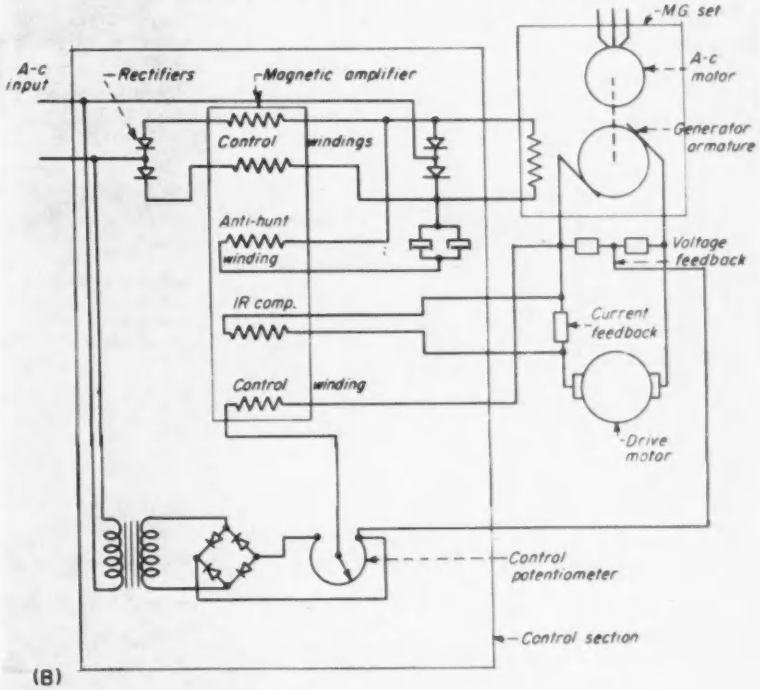
These are used on slitters, winders, calenders and presses in the paper industry and on veneer unreeling, extruders, mixers and test stands. They are also used in power stations where close automatic control of high horsepower is necessary, and in small marine drives for tug power plants to give quick speed response for maneuvering.

A special application is in a testing machine where the speed range is 15:1, the load has high inertia and the specifications calls for cycling. The full speed range is not required for any given cycle but regulation of ½ percent is specified. In order to meet these specs one motor of 250 hp and one two speed motor of 500 hp is used. At the lower speeds the low speed motor drives through the two-speed unit. For the higher speeds the low speed unit is uncoupled and one of the two speeds of the high speed motor is used. This allows the clutch to operate at its best speed and so give the close regulation required. A water cooled clutch is used to take away the heat, and current limit control protects the drive motor during the long accelerating periods and also controls rate of acceleration by torque control. This is an application where all the built in controls are used with pre-set speeds, torques and cycling all automatically controlled.



Louis Allis Co.

Fig. 7—Typical commercial rotating drives with control (A) by thyratron regulation of motor and generator field; (B) by magnetic amplifier regulation.



Motor-Generator Drives

The third type of drive uses rotating equipment in the power section, and a form of Ward Leonard control system and either electronic tubes or magnetic amplifiers in the control section, Fig. 6. In this an a-c motor drives a generator and an exciter. The exciter is used to control the field of the generator and supplies the field of a main d-c motor. The generator armature is direct connected to the motor armature and speed control is obtained by controlling the generator voltage. As the generator field voltage increases the generator voltage increases and vice versa. Thus, by controlling the field of a generator the voltage across the armature of a large motor is controlled; this is the transition from low level control to high power control in

this type of adjustable speed drive.

Commercial drives Fig. 7, use automatic control to adjust the motor armature voltage. One is an all electronic control using thyratrons for the motor field and for the generator field. This eliminates the exciter but is only used on low powered drives. On the larger drives, exciters are used and their field controlled by the electronic controls.

The second unit uses a magnetic amplifier for the control element. This has windings for voltage control, anti-hunting current limit, and IR compensation. The resultant of these windings controls the power to the generator field. At present this system is limited to small drives and requires exciter generators when large horsepower is involved.

It can be seen, that as these elements are cascaded to get the necessary power output, a lag factor builds up due to the reluctance of the various field coils and generator build-up. When the control works into a generator field without booster exciters, the response is rapid enough for most applications but where large power and rapid frequency response is required this lag will cause hunting or poor regulation characteristics.

During the war special multi-winding d-c control generates were developed and brought to a high state of perfection. These have the characteristic of self forcing buildup, two or more control windings and special core steel to reduce hysterisis affects. These specifications give a unit that changes its output voltage rapidly and takes very low power input for control.

There are two commercial units employing this principle, Figs. 8 and 9. Known under the trade names of Rototrol (Westinghouse) and Amplidyne (G. E.), they are generally called rotating regulators.

The Rototrol is a specially built series d-c generator with its field in series with the armature. The field is adjusted by an external resistance so that its resistance gives a line tangent to the saturaton curve of the generator (line *C*, Fig. 8). If the resistance were greater, the generator would not build up (line *A*) and if it were lower (line *B*) it would build up to the intersection point. Either of these conditions gives stable operation.

Operating along line *C* is actually an unstable condition as the voltage is floating and can assume any value along the ordinate. The control windings are used to stabilize the operation and fix the output voltage at some desired point, but it can be seen that the power necessary to shift or adjust the voltage is very small due to this floating condition. Of the two control windings, one is used as a reference winding and the other as a feedback winding. They buck each other so that at equal voltages they have no control effect. When the voltage differs, the differential controls. This is the simplest of the type; many more windings can be used, and can be connected to give different ratios and types of control. Likening this drive to the previous types, the control windings are the control section, the series field winding the operator, and the armature the power section.

The Ampldyne, Fig. 9 uses a similar principle in that the control fields act as stabilizers and supply little power. The power build up comes from a pair of shorting brushes.

When the field is excited and current flows in the armature, an armature flux, at right angles to the field

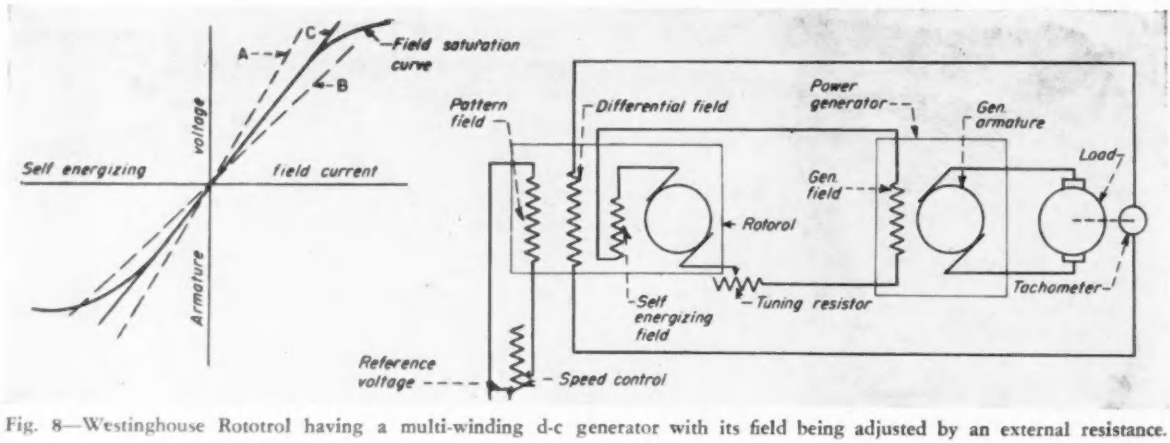


Fig. 8—Westinghouse Rototrol having a multi-winding d-c generator with its field being adjusted by an external resistance.

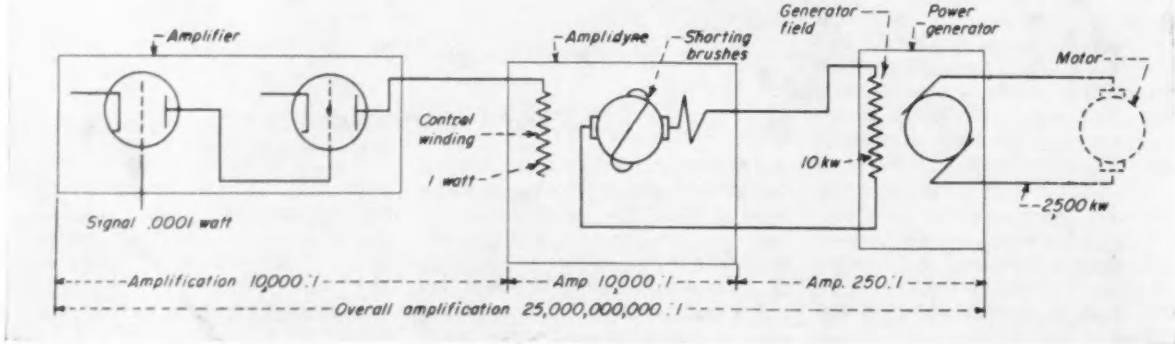


Fig. 9—GE Amplidque drive with a multi-winding d-c generator, special field structure, and a pair of short circuit brushes that pick up field flux and are the basis of power amplifications of about 10,000 to 1 compared to 250 to 1 in ordinary generators.

flux, is created in the field poles. This armature flux is proportional to the armature current and in a normal d-c generator is about equal to the excitation flux. In the Ampldyne, this flux is used to generate the load voltage by the addition of an extra set of brushes and special field structure. Two voltages are induced in the armature coils, one from the field coils and one from the flux set up by the armature current. These voltages are phased at ninety degrees to each other.

To get amplification or a large output for a small input, the brushes that pick up the voltage from the field flux are shorted. This reduces the resistance in this circuit to a low value for small field excitations, large armature currents flow. These large armature currents produce a large quadrature, right angle, field flux. The armature windings under this field now have a high voltage current or a large power output. The amplification of the system is about 10,000:1 as compared with 250:1 for a conventional generator. This allows extremely low wattage input for large power outputs.

The electronically controlled motor-generator systems have many of the same applications as the all-electronic drives but usually the two systems do not compete as each has its own horsepower range where price is the primary factor. In general the frequency response is not as good due to the inertia of the generator field and armature, as compared with the inertia of vacuum tubes, but again in the horsepowers where these are used, this is not usually important. They do have the feature of regenerative braking which is not easily obtained on the vacuum tube type drives, and this allows them to maintain as close as 2 percent regulation with an overhauling load.

They are used for calendering, wire drawing, pumping, machine tools, testing machines and paper machines where their higher horsepower is required.

The elite of these drives are those using self-forcing generators or rotating regulators. All control and operator functions have been designed into one compact control package which has low inertia and extremely sensitive control. The regulators can be used as primary drives for low horsepower applications and as forcing controllers for medium and high horsepowers. In other words they are both drives and controls with the frequency response and sensitivity of control elements.

One use of these is in high power servos used for gun directing on naval vessels, land artillery and airborne weapons. In industry they are usually used on high powered drives with multiple control windings for the integration of various control signals.

A complex controls application is on a slasher drive in the cloth industry. The whole drive is under the control of the operator at the control panel, but the beam winding drive is under the automatic control of a forcing generator. The control fields interact to slow the drive motor down as the reel builds up and increase the torque to maintain yarn tension. The actual tension is manually set and then automatically maintained. In like manner the operating speed is selected and maintained automatically. These drives also use moisture control on the yarn to automatically control the operating speed for the desired yarn regain.

They are also excellent on high powered high inertia loads for they give smooth acceleration with current limiting. This is typical of mine hoists, centrifugal casting machines, centrifuges and tire testing machines. The latter has a fly-wheel with a WR^2 of 10,000,000 lb ft^2., and requires an accelerating torque equal to 400 hp at 350 rpm to reach maximum speed in 60 minutes. The control maintains a constant current during this period and increases the voltage as the drive motor speeds up. It is also arranged for regenerative braking when the usual tire break is not used. During tire braking cycles when the generator is disconnected from the motor, the generator voltage is always matched to the motor counter emf so the system can be reconnected at any time for regenerative braking or flywheel speedup.

Another interesting application is on a large boring mill where the control unit operates to match the feed screw motor to the table speed. The table drive has a synchro and the feed screw drive has a synchro and any phase error gives a control signal which the drive corrects by changing the feed screw drive speed. This control is also arranged to give closely regulated speed control.

Advantages to the Machine Designer

This outline gives some idea of the general operation of these variable speed drives and brings out the methods of control. The control is the heart of any variable speed drive and its regulation, ease of operation and flexibility determine the versitility of the whole unit. Where automatic control is operated by transducers, it is essential that the primary control elements can operate at low power and that the control mechanism be self regulating. In other words, some form of feedback or closed loop system must be used that compares the output with the input and automatically corrects errors.

All these drives have this feature as an integral part of the control and so simplify the design problem for the engineer. The design of a feedback control system is not simple and for a non-electrical designer, practically impossible. These units offer a package for integration into a design. All that is needed is a suitable transducer to change the operating constants into either mechanical or electrical signals, of low level, that will operate the control potentiometer of the drive. Once the signal values are set up the drive will accelerate or decelerate at a set rate, the speed hold accurately over wide load fluctuations, or synchronize in with some other operation.

An analysis of the control circuits shows that the basic elements of voltage and current control are standard features. The removal of these controls to a remote location and the modification of them to fit an application resolves into a minor alteration of a stock item. This is why these drives are such versatile design components, for they can be modified at low cost to fit special requirements. Most of them are built as subassemblies and rack mounted so that each section is a unit prewired for the addition of various accessory controls. When ordered, the necessary subassemblies can be mounted and interconnected without special engineering.

In this fashion drives from fractional horsepowers up to hundreds of horsepower can be assembled from stock items. These are rarely shelf items but still are components that are fully engineered and field tested. Costwise this means the equivalent of a custom drive at litle more than a stock drive of equal speed and power range.

Another feature of these units is the various controls that can be added in the control circuit to give the desired operating characteristics. As the main speed and current controls are small variable resistances, any speed in the operating range can be preset and switched in by disconnecting the operat-control and substituting the

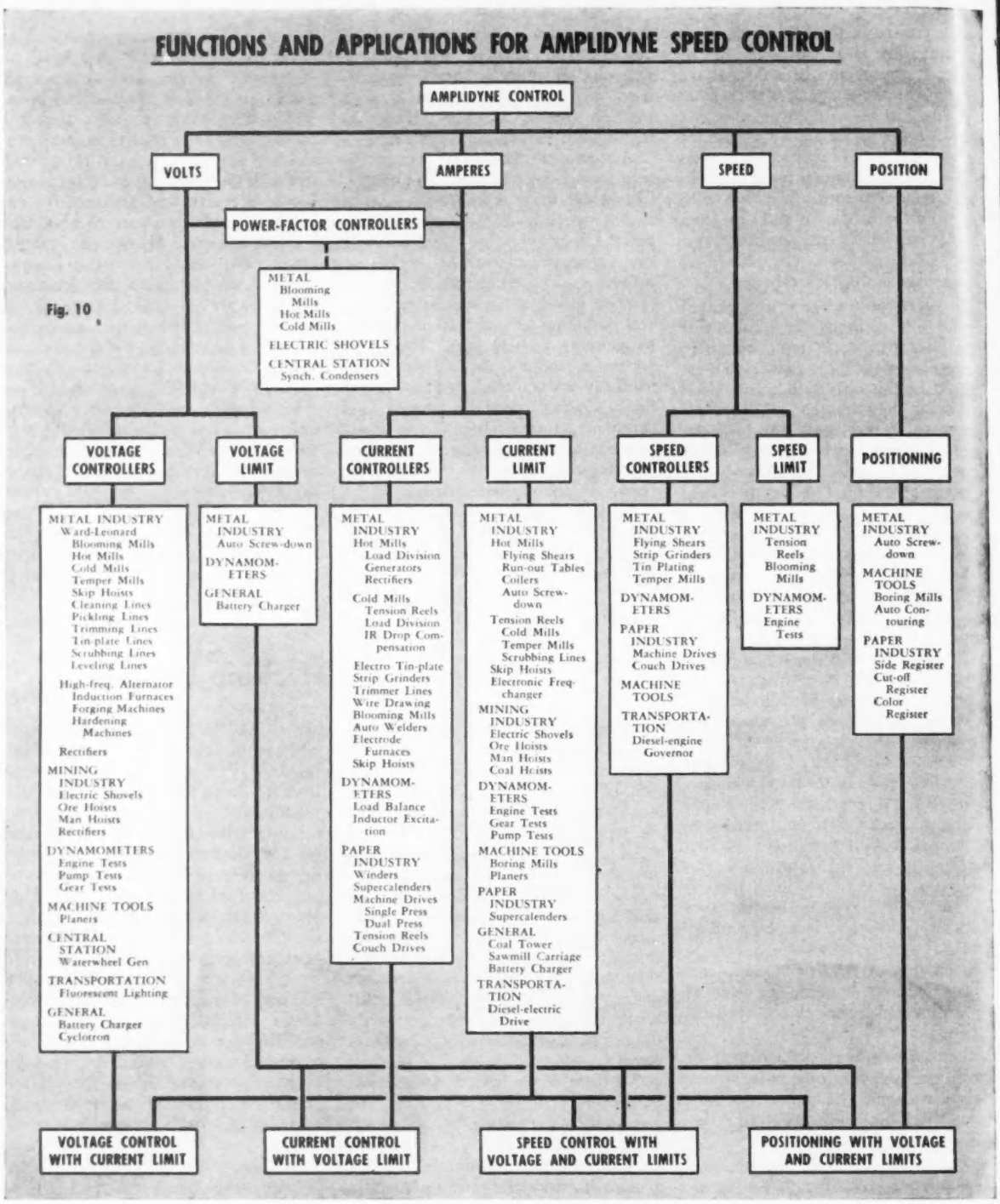


Fig. 10

preset resistance. Such control functions as inching, creeping, and multiple operating speeds can be preset and switch selected. In like manner the current limit, which controls torque and acceleration, can be manually adjusted or have preset values selected by a switch.

These drives are well accepted by industry and have found wide use in the heavy industries. They are becoming standard in such industries as steel, paper, textile and machine tools where extreme flexibility and critical control is necessary, Fig. 10. The Rototrol would have similar uses and the other drives could also be used for many of these applications that fall within their horsepower and frequency response characteristics.

The importance of this general listing of industrial applications is not to show what is available in stock items on these variable speed drives but rather to show their versatility. Their design and their built-in automatic controls make them adaptable to practically any type of application where variable speed drives would be of advantage.

TECHNICAL NEWS

Testing:

High Frequency

Magnet Properties

ONE OF THE SIGNIFICANT FACTORS in reducing the size of electronic components has been the development of new magnetic materials like ferrities and powder irons. But designers have been handicapped in making the most effective use of these materials by a lack of authoritative data on their properties, particularly at high frequencies.

What's been needed is a standard for determining the r-f permeability and the loss factor (or complex permeability), two factors that best describe the behavior of magnetic materials at high frequencies. Now the National Bureau of Standards has established a primary calibrating standard for determining these properties in the frequency range between 50 kc and and 30 mc.

The standard is a coaxial line of variable length constructed to dimensions of extremely high accuracy and measurement depends on the change in inductance of the line when a sample of magnetic material is inserted. The characteristics of magnetic materials are determined in terms of variations in length of the line. Accurately calibrated in 19 one-inch steps and including a micrometer system that permits the measurement of variations to within 0.0005 in. along the 20-in. length, the line is made from non-magnetic materials to reduce effects from extraneous magnetic fields.

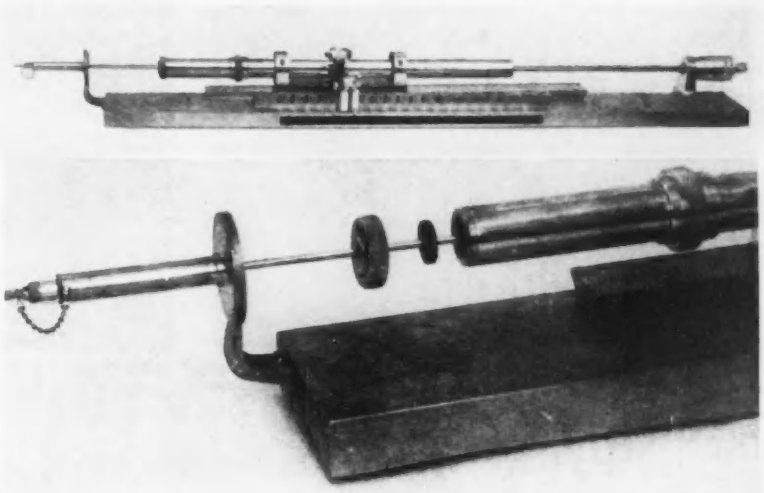
Here's how a typical investigation is made:

The output terminal of the coaxial line is connected to the "unknown" terminal of an r-f bridge suitable for measuring inductance in the frequency range at which the material will be used. The bridge is then balanced with no sample in the line and the coaxial segment extended to its fullest length.

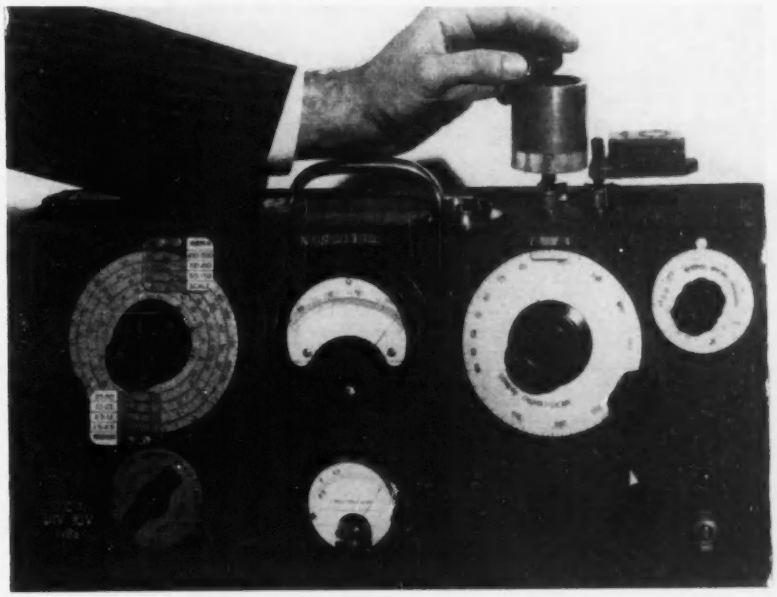
A sample of the magnetic material is ground into a coaxial disk that completely fills a section of the space between the conductors of the coaxial line. This is inserted on the center conductor on the line and held in place by a metal cap that short circuits the end of the line. The resulting bridge unbalance is adjusted to the original conditions by manipulation of the resistance reading arm of the bridge and a reduction in the length of the coaxial line.

The variation in the length of the line is directly proportional to the permeability of the magnetic material relative to air and constitutes a primary method of measurement. The difference in resistance readings is a measure of the loss factor of the material and is limited only by the inherent accuracy of the bridge instrument.

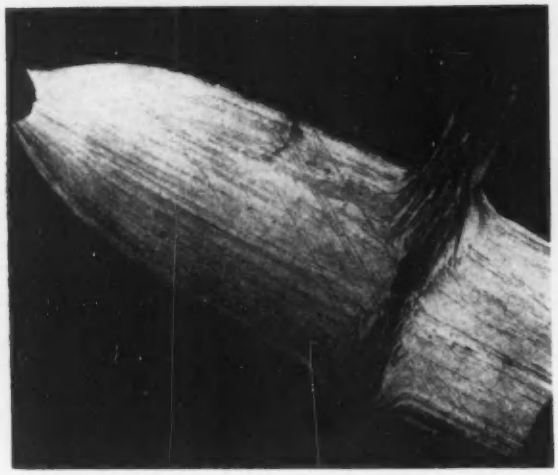
For production control, NBS has developed a secondary standard that does not use such precise calibration equipment. This r-f permeameter consists of a two inch hollow brass cylinder fitted with shorting covers at both ends. The top cover is removable to admit sample materials and is made of



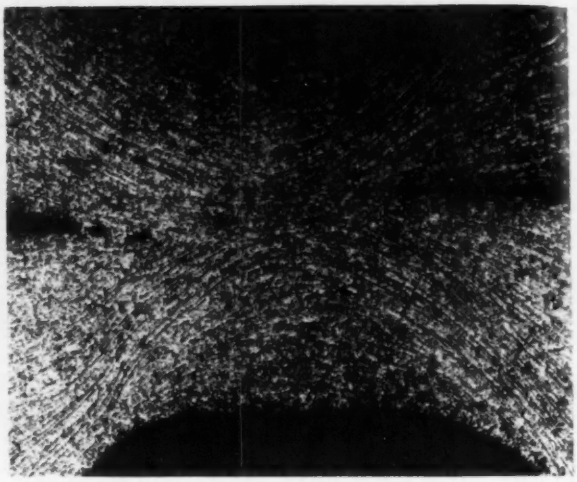
COAXIAL LINE of variable length is new standard for measuring the high frequency properties of magnetic materials. Closeup of standard shows how ground disk of magnetic material is placed on the central conductor. Metal cap short circuits end of line.



R-F PERMEAMETER for production control uses test sample in the form of a toroid. Unit is only two inches long. Large case is Q-meter used with the permeameter.



IN TENSILE TEST, wire failed (left end) while Koldweld remained intact showing cold working effect.



MICROPHOTOGRAPH of Koldweld shows how pressure causes an interflow of metal that makes a homogeneous bond.

Pressure Welds Non-Ferrous Metals in Cold Process

IN A NEW PRODUCTION PROCESS, non-ferrous metals like aluminum and copper can be welded without heat, flame, or electrical current, and without acids, fluxes, or chemicals. Call Koldwelding, the new process uses pressure to cause a flow of molecules that makes a bond with greater tensile strength than the original metal.

Unlike conventional welding techniques, in which heat anneals the metal and reduces its tensile strength, Koldwelding work-hardens the metal to improve its strength. Using special tools developed by Utica Drop Forge and Tool corporation, the cold bond can be made in a few seconds.

At present, two big uses are seen for the process; welding sheet and wire. Advantages in wire joining include: the production of a bond in the same gage as the wire itself, elimination of electrolysis, and in power transmission cables the elimination of clamps that tend to loosen and cause radio interference.

In structural wiring, this process reduces fire hazards since the joint becomes integral with the wire itself and is not subject to failure by twisting or breaking. In addition the electrician uses no flame, chemicals or electrical current in making the bond.

The main advantage in welding sheet with Koldwelding is improved strength of the bond. Under test, the metal itself will tear before the bond fails.

Koldwelding was originated by the General Electric Company Ltd. of England and the sole licensee in the United States is the Koldweld Corporation. Utica Drop Forge and Tool Company have made arrangements to manufacture equipment to use the process. Now, Utica has two tools in production, one for Koldwelding wire, and the other for sheet. Both are portable and operate basically on the pliers principle. The company also plans to make a pocket tool about the size of a standard pair of pliers for the electrical contractor and the home owner.

---

beryllium copper to obtain a springy yet electrically tight fit. The bottom cover is permanently fixed and has a central spike which forms the center conductor of the coaxial line. A shelf made of low-loss insulating material separates the upper third of the cylinder from the lower portion.

The meter uses toroidal ring samples. An r-f bridge or Q-meter is balanced with the toroid in place and with a proper number of windings on it. Then the windings are removed and the magnetic sample toroid without windings is placed on the shelf and the impedance bridge is rebalanced. The variation in input impedance, as read from the bridge, indicates the quantity from which the permeability and loss factor can be computed.

A simple adaption of this permeameter can be made to permit the measurement of the temperature coefficient of magnetic materials, a property which indicates the stability of these materials at high temperatures.

Used in the proper place, these instruments will permit the designer wider latitude in the use of magnetic materials. Generally, he wants a material with high permeability and low loss factor. But in some applications the losses are unimportant and in others he can use high losses to advantage.

U. S. Will Push Titanium Expansion

WASHINGTON—Government officials plan to deal themselves into the titanium picture in an effort to push production up to 22,000 tons a year by 1956. The speed up stems from increased interest by the military in the metal.

Now the Navy has joined the Air Force in wanting to take advantage of titanium's corrosion resistance, strength-weight ratio, toughness, and the other properties that had metallurgists acclaiming it a "wonder metal" (PRODUCT ENGINEERING, Nov. 1949, p. 129; Nov. 1951, p. 164).

Originally, Washington planners hoped to boost titanium capacity from its present 2,000 tons a year to 10,000 tons by 1955. The new schedule is a compromise with that proposed by the Munitions Board.

The Board, which has been working with industry on titanium production, recommended an increase in capacity to 35,000 tons a year. But the Defense Production Authority put the brakes

on such a large program. For one thing, such a proposal would require $140 million for equipment and an additional $525 million to buy the metal. DPA doesn't want to sink that much money in present day production techniques. They're hoping that someone will come up with a new low-cost process that will put titanium in the same price class as aluminum.

Even the 22,000 tons expansion program is going to take plenty of government encouragement, including, government money. For titanium, currently costing $5 for sponge metal to $15 per lb for sheet, suffers from an ailment common to all new materials. Producers hesitate to expand production in the face of uncertain demand, and the dangers of obsolescence of the present high-cost reduction process. On the other hand, consumers are reluctant to start using it in the face of uncertain supply.

Here is how government aid will try to push the titanium expansion program with the high-cost Kroll magnesium reduction process: the government will loan cash to producers who are willing to build up plants and equipment, and the producer can repay the loan in metal instead of cash. The government will grant rapid tax write-off privileges. And one of the most enticing lures being dangled before prospective producers is the government's offer to cancel indebtedness if the Kroll equipment becomes obsolete during the life of the contract.

Titanium research is currently one of industry's hottest competitive races with about 40 companies entered. So far results have been disappointing. One company has five different processes in pilot plant operation; however none of them are ready for commercial use. Another company feels they have a satisfactory method for electrolysis of a titanium compound but they aren't willing to put it into large scale production.

Some of the problems yet to be solved in production processes are: 1) how to get a low-cost continuous production process for separating metal from its ores. 2) To develop a method to prevent contamination of the metal when it's hot or molten. 3) To develop improved methods for working, casting and welding the finished metal.

If these are ever resolved, the titanium picture would be bright. Titanium ore is plentiful; it's the ninth most abundant element in the earth's crust and is four times as plentiful as zinc lead, and copper combined. Known North American reserves of ilmenite, the major source of titanium ore, are sufficient to support annual production of 500,000 tons of metal for the next twenty-five years.

But right now, the price and supply is such that designers can use it only for top priority jobs like jet engine components. Industry would like to try it in many kinds of applications:

In aircraft: for structural parts and medium temperature engine and surface applications, replacing heavier metals like stainless steel.

In marine corrosion applications: to replace copper-base and nickel-base alloys that have been hard to get.

In chemical equipment: applications like pipes and tubing, condensors, shafts, containers, plumbing fixtures, and laboratory equipment.

In ordnance equipment: to replace steel in protable or mobile equipment, particularly that which is airborne.

Foam Plastic Adds Strength to Aircraft Structures

LOCKHEED AIRCRAFT CORPORATION has developed a foam plastic (PRODUCT ENGINEERING, April 1951, p 192) for use as a structural stiffener in cavities of complex parts. Called Lockfoam, the new material is poured like molasses into hollow parts and then changes to a solid that resembles angel food cake in texture.

Most important properties of this material are its good strength and its ability to adhere, without glue, to metals, wood, paper, and fabrics. Varying additives to the plastic permit the producing of Lockfoam for specific purposes from rigid forms capable of withstanding pressure in excess of 200 psi, to forms as flexible as sponge rubber. To test the bonding properties of the material, Lockheed engineers exposed the bond between the plastic and an aluminum skin aileron to weathering for two years without any appreciable deterioration.

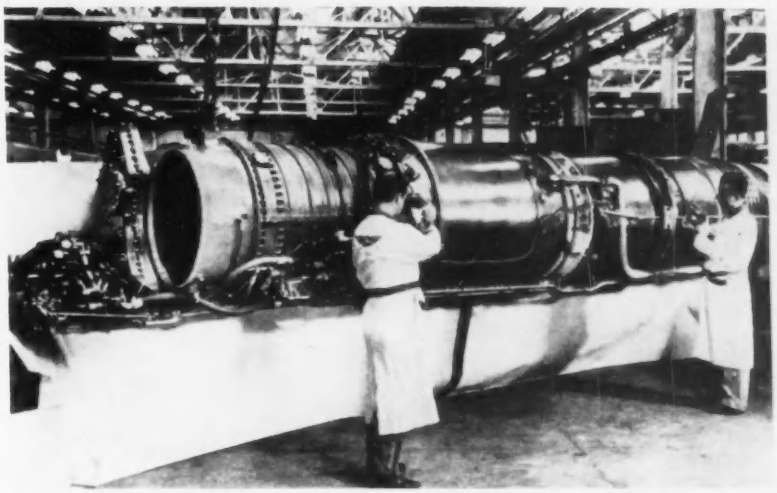
While Lockfoam passes radar waves without interference, Lockheed claims that it provides excellent insulation against shock, heat, cold, sound, vibration, and electricity. Because of its good moisture resistance, the aircraft company believes it will also serve as good building insulation.

Density of the material can be varied from 1½ to 35 lb per cu ft.

In its liquid state, the material can be poured-in-place, sucked into cavities through holes too small for pouring; or flowed into casting blocks and carved to size. The material sets under ordinary room conditions without heat or special equipment.

Lockheed is now using the material to give strength and stability to such odd shaped parts as: ailerons, rudders, elevators, wing trim tabs, and rocket exit doors on the F-94 C Starfire; wing shock absorbing structures and antenna housing in the PRV. They are also using it as insulation in the cabin ventilating system of the Super Constellation.

Lockheed has licensed the American Latex and Nopco Chemical Companies to manufacture and market Lockfoam.



NEWEST CLAIMENT for the title of the world's most powerful jet engine is this Westinghouse Turbojet aircraft engine now in production for the U. S. Navy. Almost 25 ft long and weighing 3,500 lb, the engine uses axial flow design and an afterburner to develop the equivalent of 25,000 hp. Engine will also power aircraft accessories.

Special Report: Powder Metallurgy in Sweden

THE DEVELOPMENT OF POWDER METALLURGY in Sweden has been influenced by two facts: Sweden is famous for its iron and steel industries, and the Swedish engineer is recognized for the skill of his mechanical design. As a result most of the powder metallurgy parts used in the Scandinavian country are made from iron and steel powders, and are characterized by uniqueness in design.

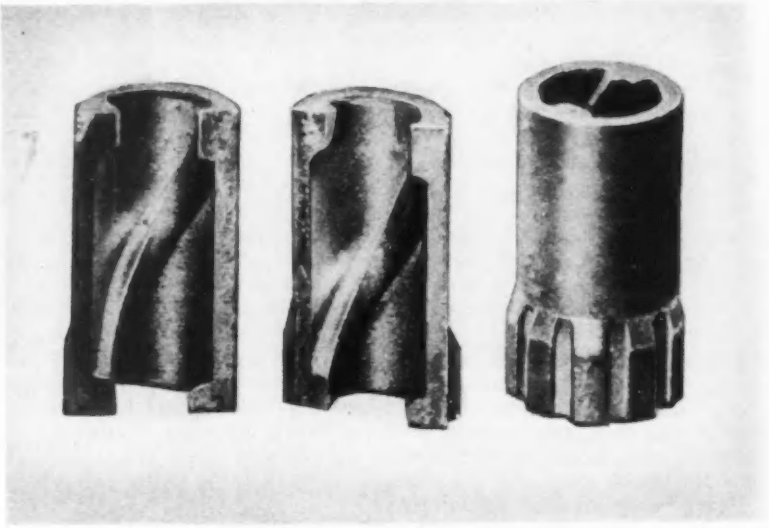
According to Dr. Henry H. Hausner, Sylvania Electric Products, Inc., who has just completed an inspection trip of Swedish facilities, this is the current powder metallurgy picture in Sweden:

▶ **Sponge Iron.** Most of the powder metallurgy producers use sponge iron powder, a low-price, high quality iron powder that has been made by Hoeganaes-Billesholmes A.B. since 1911. In 1951, over 5,000 tons of Hoeganaes powder were used in Europe, and more than 116 ton were used in the United States, representing almost 60 percent of American iron powder consumption). Unofficial observers estimate that this company produces about 50 percent of all the iron powder used in the world.

Husqvarna Vapenfabriks A.B. is a major producer of electrolytic iron powder (750 tons in 1951). The company uses powdered iron parts in the manufacture of bicycles, sewing machines and household appliances like washing machines and refrigerators. They use a double pressing and double sintering process that permits the production of structural parts with close dimensional tolerances and good finished surfaces. Such parts have a high density, a tensile strength of 40 to 50,000 psi, and an elongation of 30 to 36 percent.

▶ **Self Lubricating Parts.** A. B. Glissa in Stockholm has concentrated on the manufacture of sintered structural parts like self-lubricating bearings and other self-lubricating parts. In general, Glissa's processes for compacting powder are simpler than those used in the United States, although they also use Stokes Presses. Compacting dies are usually more complicated and produce unusual designs. **Dr. Hausner** reports that he was particularly impressed by the almost unbelievably complicated shapes this company was turning out.

Other major producers of sintered parts include: A. B. Svenska Metallverken, Vasteras, producers of sintered plates for storage batteries and frictional materials; Svenska Diamantbergborrnings A.B., manufacturer of high quality diamond tools is an extensive user of the hot pressing method of powder metallurgy; and such companies as Lumalampan A.B. and A. B. Kanthal are using powder metallurgy in other products.



THIS BUSHING with a spiral spline made by A. B. Glissa, Stockholm is typical of the complicated parts produced in Sweden by Powder Metallurgy.

▶ **Other Materials.** In the electrical industry, Surahammars Bruks A.B. have developed sintered electrical contact materials. And Dr. J. Heuberger, manager of the Glissa works, has pioneered in the production of copper-graphite generator brushes by powder metallurgy techniques.

Five factories in Sweden are currently making sintered carbide tools for export throughout the world. Most outstanding have been those used for rock drilling purposes.

▶ **Differences in Techniques.** Sven I. Hulthen, Chief Engineer of Hoeganaes claims that the main difference between Swedish and American powder metallurgy production is in the use of equipment. He pointed out, "In Europe, the most commonly used presses are simple, hand-operated machines. Simple hydraulic presses are used only when pressure greater than 50 or 75 tons is required."

Hulthen admitted that this necessitated the use of more complicated tools to compact parts of intricate shape in the direction parallel to the compacting pressure. The usual solution to this problem is to float the die on the springs.

Hulthen also warned that a designer should consider the end use as well as the design of sintered parts. He pointed out that neglecting to do this ruined powder metallurgy in Germany after the war because of widespread failure of parts used in the wrong applications.

New Patent Codification Goes into Effect

WASHINGTON — Improved efficiency at the Patent Office is expected now that the recent codification of the Substantive Law of Patents is in effect. While Patent Office procedure has been undergoing a housecleaning for the past two years (PRODUCT ENGINEERING, Sept. 1952, p. 203) further changes are in the cards to conform to the new law.

Most of the changes in the law deal with changes in time for appealing certain actions. Most of these have been incorporated with a view to stepping up Patent Office efficiency, while a few alterations have been included as the result of recent judicial decisions.

Patent Officials are worried about a possible flood of applications based on a mis-interpretation of the new law

that has gotten wide publicity. Rumors have indicated that new uses for well known chemicals are now patentable. But according to Patent officials this has not been true, and is not true under the new set up.

The confusion stems from a new definition of the word "process." Under the recodification it is possible to get a patent on a method of applying a chemical. Patent officials explain it this way:

If an inventor develops a process (which happens to involve the use of kerosene) for killing insects, he can patent this now. He could also get another patent on his process covering its application for killing weeds. But he cannot patent the use of kerosene or any other chemical as a weed killer or an insecticide.

BIR Cracks Down on Non-Profit Research Institutes

WASHINGTON—The Bureau of Internal Revenue has issued a new regulation that interprets "Research" as it applies to income taxes. Under this ruling which is effective on income from contracts during 1951 and thereafter, nonprofit institutes that show a profit on their commercial testing and research will have to pay taxes on these sums.

Background for the new interpretation stems from the investigation of commercial activities carried on by universities and scientific non-profit organizations conducted by the Joint Congressional Committee on Internal Revenue Taxation. As a result of this study that ran from 1947 to 1950, the Revenue Act of 1950 carried a number of provisions that would tend to tax and restrain these activities that were competitive with private enterprise.

But the law specifically excluded from taxation income derived from research in colleges and hospitals on the grounds that it was related to educational objectives. Only revenue produced by production possibilities, such as the spaghetti factory owned by New York University, was subject to taxation.

Last January BIR proposed a regulation that would prevent institutions from avoiding taxation under the guise of research programs. In September, they published this regulation which defines tax-exempt research.

The new ruling says that research does not include activities of a type ordinarily carried on incident to commercial or industrial operation. For example, the testing or inspection of equipment and buildings.

The regulation further states that "fundamental research" does not include research carried on for the primary purpose of commercial or industrial application. As a result, non-profit research institutes will not be able to claim tax exemptions on income derived from commercial testing or applied research.

Predict Big Battle

Observers in the Capitol feel that BIR's definition is just a skirmish. They think the big battle will come when laywers from the non-profit institutions and universities challenge the ruling. Their main argument will be: universities should have some benefits, such as being able to operate commercial enterprises, to raise money to replenish their coffers.

Aligned with the BIR in the fight will be the Commercial Laboratories who insist that no one should get special treatment in tax matters, especially at the expense of private enterprise.

According to the American Council of Commercial Laboratories, spokesman for most of the labs, "Research findings of tax-free institutions no matter how financed are in the public domain. And these should not be handed over to an individual firm or organization."

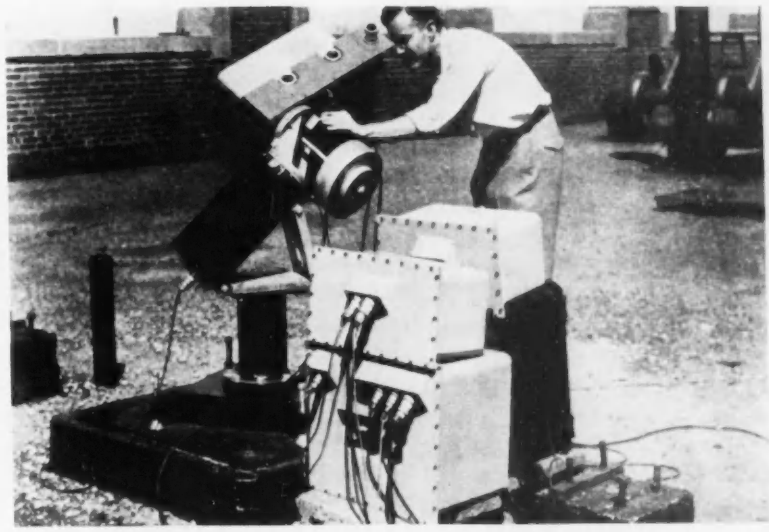
ACCL insists that the public pays part of the cost of this type research and therefore it should get the benefit.

Executive secretary Dr. Harold M. Dudley says that ACCL does not oppose non-profit institutions' work in fundamental research. In fact, they heartily agree with BIR's statement of the regulation which continues tax exemptions for such institutions on income derived from any kind of research done for federal or state governments.

Zinc Institute Emphasizes Availability

WITH SUPPLY AND DEMAND FOR ZINC at a balance, the American Zinc Institute has issued a statement to reassure industry that this metal is now available for all users. According to the Institute:

- Zinc is no longer classified as a critical and scarce material. The National Production Authority released zinc from allocation delivery and use controls on May 15, 1952. Use restrictions for consumers in the United Kingdom were removed on August 15.
- The government is making no regular purchase of zinc for the national stockpile.
- Slab zinc production in the first seven months of 1952 exceeded 1951 production in the same period by 20,000 tons. Stocks at smelters on July 31 were 97,000 tons as compared to 22,000 tons on January 1, 1952.
- World zinc mine reserves are more than twice as large as in 1931 despite continued accelerated use.



SPECTROHELIOMETER, developed by the General Motors Research Laboratories, will measure intensity distribution of the sun's energy during the day and year in an effort to determine which parts of solar radiation are most injurious to finishes.

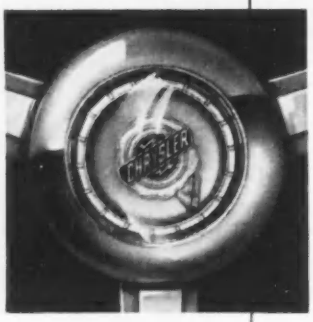
Multi-colored plastic ornaments on automobiles were hand painted luxuries a few years ago. Now, with the help of a bit of Silastic, they are mass produced to decorate even the least expensive models.

Courtesy Bay Mfg. Div., Electric Auto-Lite Co.

as a die for hot-stamping pigmented foil

SILASTIC* works

where other materials fail



One of the problems in developing this process was to find a material for hot-stamping pigmented foil. Specifications called for a die-tip that would remain resilient and not stick to the foil after thousands of impressions at surface temperatures in the range of 500° F.

After trying many materials, that problem was solved at the Electric Auto-Lite plant by using Silastic. For more than 3 years the same Silastic tips have been used, and none of them has worn out, lost its flexibility or peeled off its metal backup plate.

Retention of rubbery properties at temperatures ranging from −100° to over 500° F makes Silastic unique among rubberlike materials. Combine such stability with excellent resistance to oxidation, to outdoor weathering, and to a variety of hot oils and chemicals, and you have one of the most useful of gasketing and sealing materials. Combine those with good dielectric properties, and you have an ideal insulating material for transformers and traction motor field coils, Navy control cable, and ignition cable for aircraft and ordnance vehicles.

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Stress Chart for Spur and Bevel Gears

H. M. DURHAM

Bending stresses for spur and bevel gear teeth can be elevated graphically with this chart. Based on the Lewis Equation as indicated by the following formulas, it is applicable to cut gears of average accuracy:

$$P/F \times DP = P_e/F \quad (1)$$

$$S = \frac{P_e}{Y}\left(\frac{1200 + V}{1200}\right) \quad \text{(Spur Gears)} \quad (2)$$

$$S = \frac{P_e}{Y_1}\left(\frac{1200 + V}{1200}\right)\frac{L}{L - F} \quad \text{(Bevel Gears) Straight teeth} \quad (3)$$

$$n_1 = \frac{n}{\cos \alpha} \quad (4)$$

Where

P = Tooth load at pitch line, lbs.
P_e = Equivalent tooth load in lbs per inch of face and 1 DP
DP = Diametral pitch
S = Fiber bending stress at root of tooth, psi
Y = Tooth profile factor for spur gears with n teeth.
Y_1 = Tooth profile factor for bevel gears with n_1 teeth.
L = Pitch cone radius, in.
V = Pitch line velocity or nominal pitch line velocity in bevels, fmp
F = Face width, in.
α = Pitch cone angle

As noted in Eq (1), the pitch line loads divided by the face width give the load per inch of face based on a diametral pitch of unity. To find the equivalent load, P_e, multiply the given load by the DP. Referring to Eqs (2) and (3) it will usually be necessary to include a stress concentration factor. Curves, equations, or tables of these factors are given in most design texts.

Past experience indicates that in using the chart for spur gears, the best design procedure is to assume pitch and face dimensions, then check the resulting stresses graphically. With practice, optimum proportions can be established with a few trials.

For bevel gears, the formative number of teeth, n_1, can be found graphically in accordance with Eq (4) if the actual number, n, and the pitch cone angle, a, are known. The second example illustrates how to evaluate n_1 as well as the equivalent load, which is numerically equal to $\frac{L}{L-F}$ times the nominal pitch line load.

EXAMPLE 1.

Find the bending stresses in a 20 deg full depth spur pinion having 20 teeth and 2 DP. The pitch line velocity is 1,200 fpm and the pitch line load is 1,000 lb per inch.

SOLUTION:

P_e $(P/F) = 1{,}000 \times 2 = 2{,}000$. Thus line I is drawn as shown to intersect the 1,200 fpm line and the P_e axis. Line II drops vertically to X-X and connects with line I at the P_e intercept. The stress intercept indicates a value of 12,400 psi.

EXAMPLE 2.

A bevel gear set has a 2 to 1 ratio. The PD's for the 14½ deg pinion and gear are 40 and 80 in., respectively. The tooth face dimension is 10 in., DP is 1 and the velocity at the nominal pitch line is 600 fpm. Pitch line load is 3,000 lb per in. of face width.

SOLUTION:

From the left end of line III, which is drawn from the $n = 40$ to the Gear Ratio $= 2$ lines, an arc is drawn with O as a center. This gives a formative number of teeth, n_1, of 45. Similarly, the formative number of teeth for the gear, n_2, is 89.

To evaluate the load factor, draw line IV using a load value of 3,000 lb. This line represents the pinion radius to a scale. From point P_1, lay off the face dimension to the same scale on line IV, i.e. the length of P_1 — x is 10/20 × line IV. With P_1 as a center, draw an arc through x which gives the intercept y. Draw y-t and then draw a line through P_1 parallel to y-z. This shows the equivalent spur gear load is 3,800.

Continuing as with spur gears, lines V and VI are drawn. The intercept of line VI with the diagonal yields a bending stress at the pinion root equal to 16,800 psi.

(continued on page 205)

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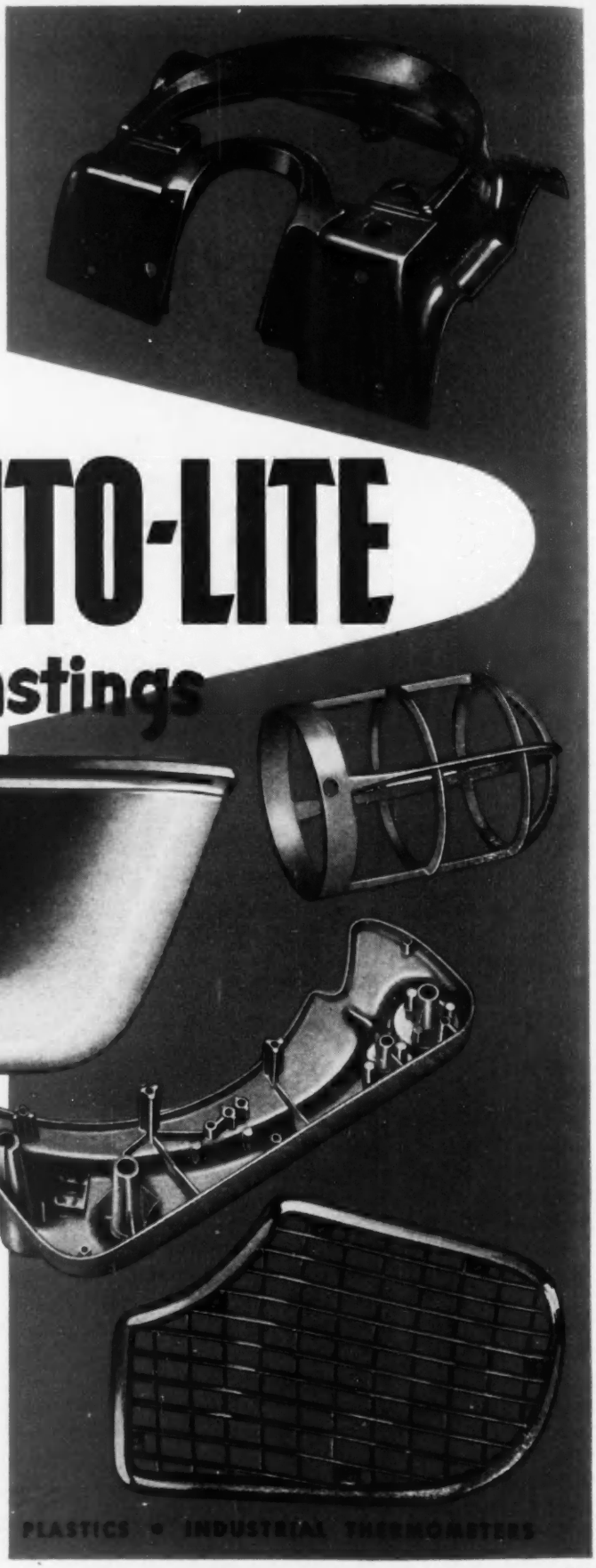

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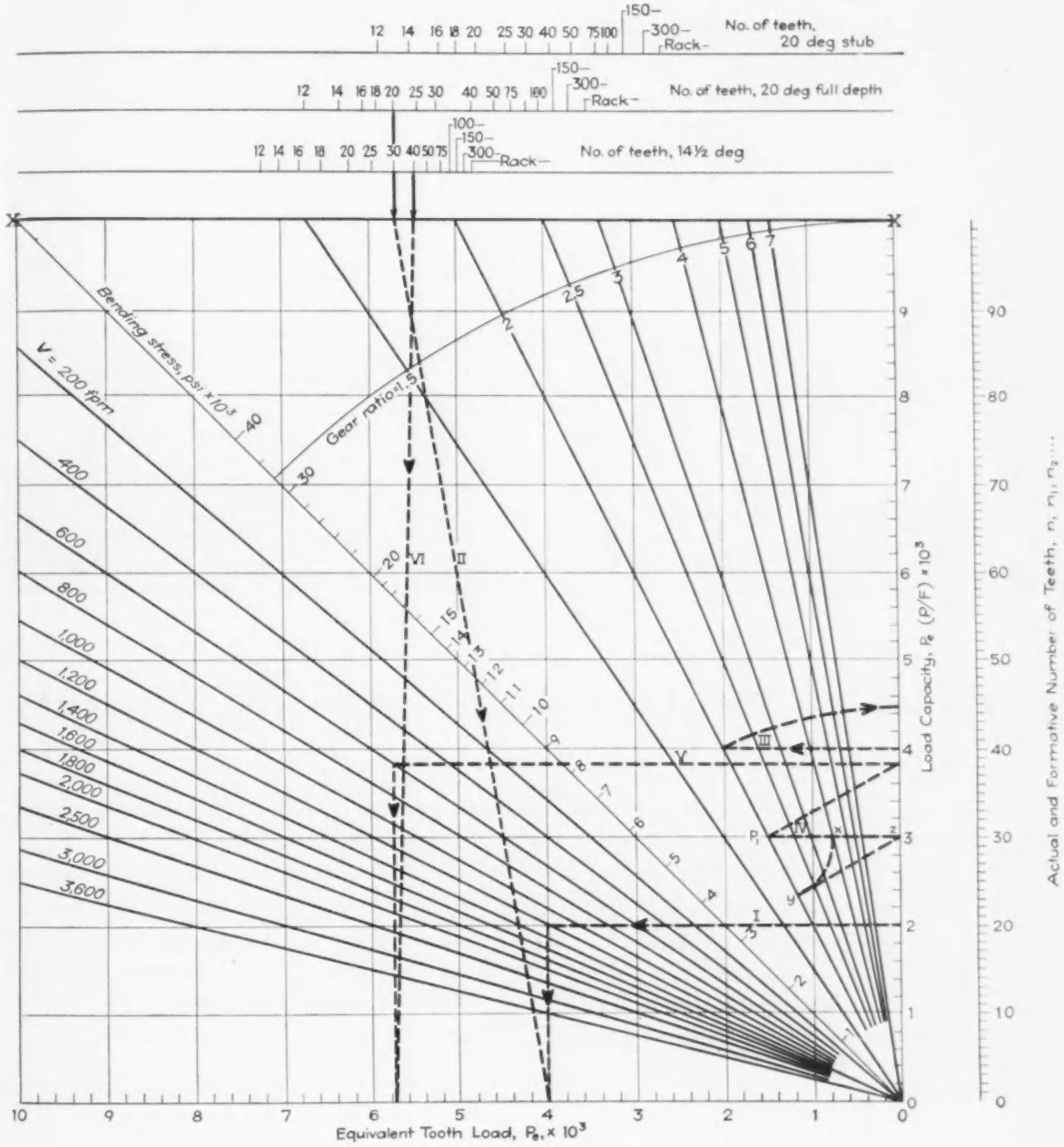
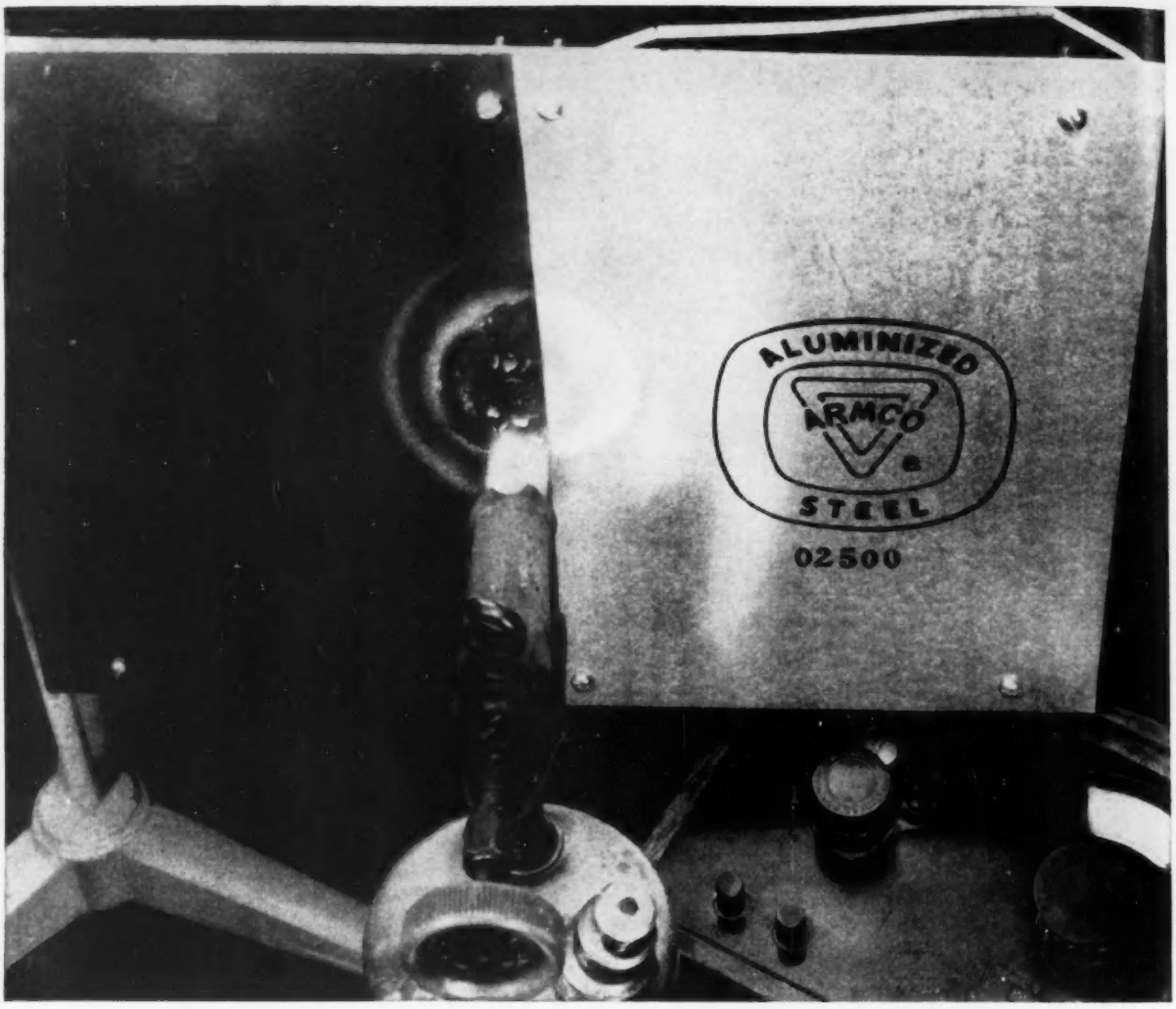
Stress Chart for Spur and Bevel Gears (continued)





Blow-torch heat doesn't "faze" this metal

The unique heat-resisting qualities of Armco ALUMINIZED* Steel are demonstrated in the test pictured here. Two sample sheets of steel, one Armco ALUMINIZED and the other a standard cold-rolled grade, were mounted side by side and subjected to *blow-torch heat.*

The ordinary steel soon scaled and pitted, but the ALUMINIZED Steel was not damaged at the end of the test.

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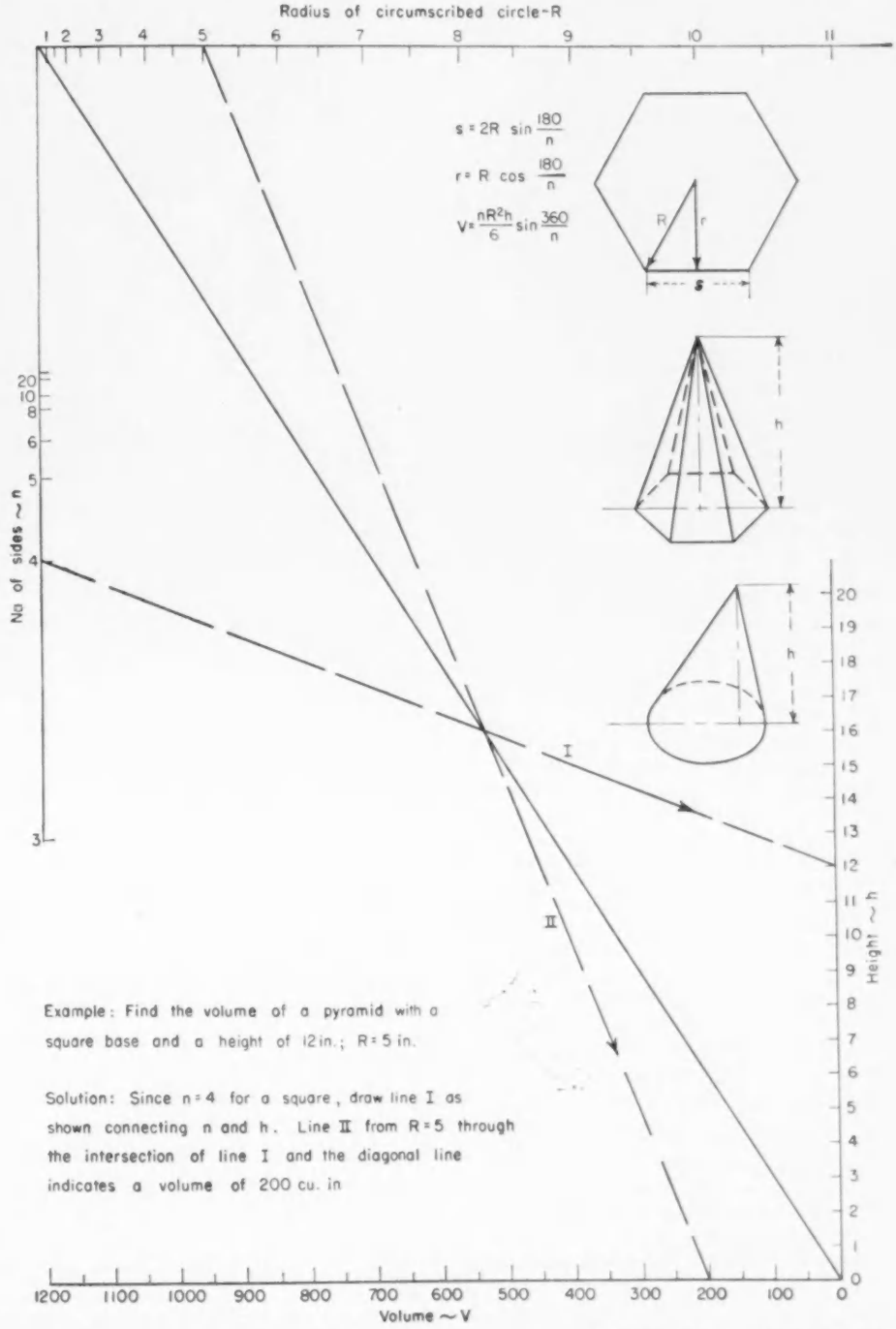
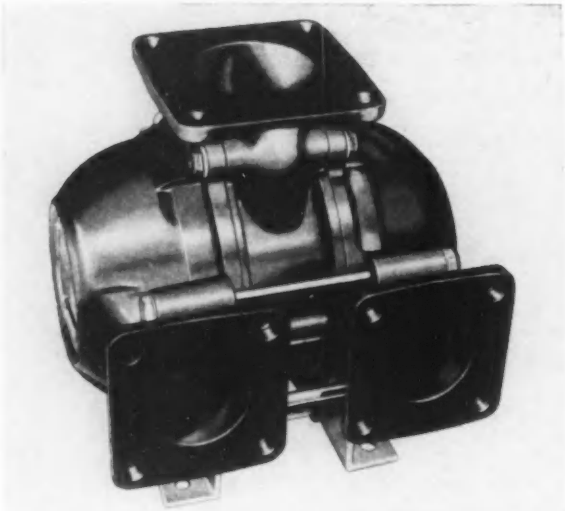
Nomograph for the Volume of Cones and Pyramids

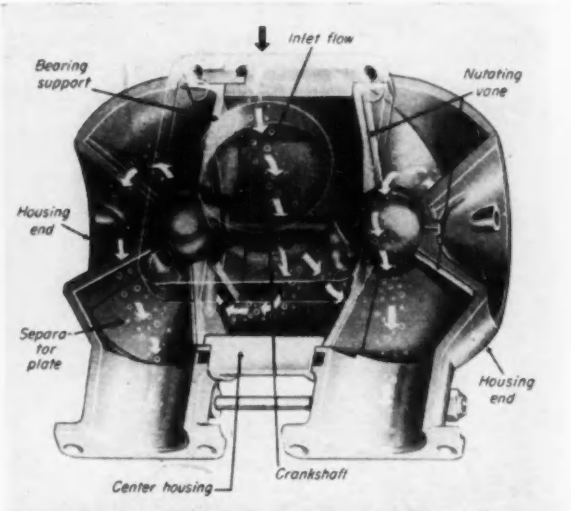
LT. S. R. HELLER, JR., BUREAU OF SHIPS, U. S. NAVY DEPT.*

Volumes of cones and pyramids whose bases are regular polygons of any number of sides can be calculated with this chart. Use is not limited to right cones or pyramids.


Radius of circumscribed circle-R
1 2 3 4 5 6 7 8 9 10 11
$s = 2R \sin \frac{180}{n}$
$r = R \cos \frac{180}{n}$
$V = \frac{nR^2h}{6} \sin \frac{360}{n}$
R
r
s
h
h
No of sides ~ n
20 10 8 6 5 4 3
I
II
Height ~ h
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Example: Find the volume of a pyramid with a square base and a height of 12 in.; R = 5 in.
Solution: Since n = 4 for a square, draw line I as shown connecting n and h. Line II from R = 5 through the intersection of line I and the diagonal line indicates a volume of 200 cu. in
1200 1100 1000 900 800 700 600 500 400 300 200 100 0
Volume ~ V

* *The opinions are those of the author and do not reflect the opinions of the Navy Department or of the Naval service at large.*





Positive Displacement Liquid Flow Divider

THE POSITIVE displacement unit known as the ratio-flo, divides a flow of liquid into two separate flows at a predetermined ratio, or combines two separated flows into one, also at a predetermined ratio. The flow divider consists essentially of two nutating vanes of the type usually found in water meters which are connected by an offset crank shaft that rotates as the vanes nutate. This causes the two vanes to operate exactly together and permit accurate division of flow. The unit is designed for a maximum outlet differential pressure of 85 psi.

The ratio of the two divided or joined flows can be predetermined to fit the needs of any given system, and the ratio is automatically held to a strict tolerance. Pressure drop through the unit is low, and the internal parts are arranged so that a restriction occurring down-stream of the unit results in an immediate pressure increase in the restricted line with only slight effect on the up-stream pressure. Where such a feature is required, automatic bypass can be included in the design of the unit with the addition of one part.

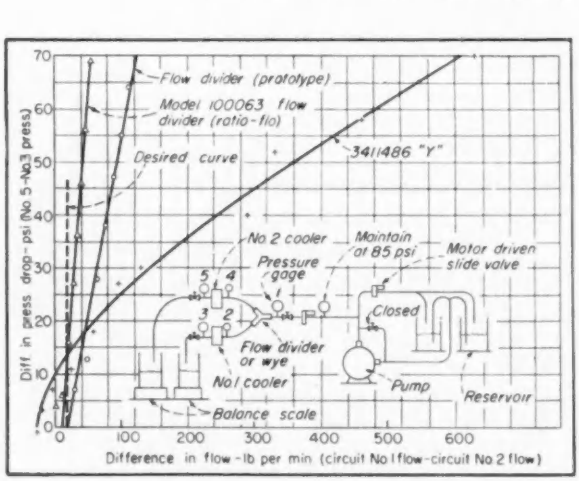
Unusual features of the ratio-flo are: very low pressure drop; accuracy; simplicity (three moving parts); and the pressure increasing effect that occurs in the outlet line with the greatest pressure drop. Under this condition the opposite valve becomes a pump which transmits torque through the crank shaft to the vane on the side with the restricted outlet.

The units are completely automatic, can be mounted in any position, require no maintenance, and are made in any line size, one inch or more in diameter. All normal fluid system pressures and flows can be handled without difficulty. There are no connections or controls, other than the plumbing attached to the unit. Inlet and outlet parts can be rotated in 45 deg increments. Weight of the unit is 2.3 pounds and it is light enough to be supported only by the fittings attached to it, but is designed so that it may be attached to any adjacent structure.

A typical installation showing the proportionate division of flow is an aircraft lubricating system. In this case the scavenger pump taking oil from the engine forces it through the ratio-flow unit which sends an equal flow through dual oil coolers regardless of any varying pressure drop. The results are that congealing in either cooler is minimized by forced flow, and a more accurate control of cooler operation is possible. Another installation is the combining of two flows from wing-tip fuel tanks.

The ratio-flo units may be used in fuel of all types, oils, hydraulic fluids, water, alcohol, and other fluids.

Wm. R. Whittaker Co., Ltd.,
915 N. Citrus Ave., Los Angeles 38, Calif.



Hydraulic Surge Damping Valves

The surge damping valve is a normally closed valve that opens when pressure is applied to the inlet side. It allows a gradually accelerated flow through the valve until fully open. After the period of acceleration, free flow is maintained as long as the fluid continues to flow through the valve. When the flow is interrupted, the valve resets and is ready for the next operation.

An unusual feature of the valve is that it will open at a slower rate of speed when high pressures are in effect than at lower pressures when the valve is subjected to sudden surges of fluid. Also, the rate of opening will increase as the pressure in the outlet line of the valve approaches that at the inlet side of the valve.

The valve is constructed with a spool which is normally held closed with a spring to prevent flow from the inlet to the outlet. But when pressure is applied to the inlet, the spool moves toward an open position. The rate of spool movement is controlled by a small pressure responsive valve, and is controlled by the difference between the outlet an dthe inlet pressures. This results in the difference in opening speeds at various pressures.

Less than a second is consumed in the operation of the control. The time consumed for the operation of the valve is no greater than the lost motion of shock when no surge damping valve is used, as is shown in the oscilloscope readings at right.

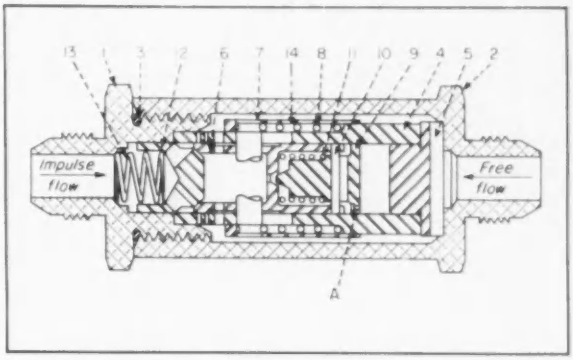
The industrial model, the larger valve in the illustration, is built in two sizes, $\frac{1}{2}$ in. and 1 in. threaded internally on each end. They are listed as model E-112 P-8 and E-112 P-16, and may be used for circuit requirements to 5,000 psi. With the use of bushings, they may be adapted to pipe or tubing of any size from $\frac{1}{4}$ in. up.

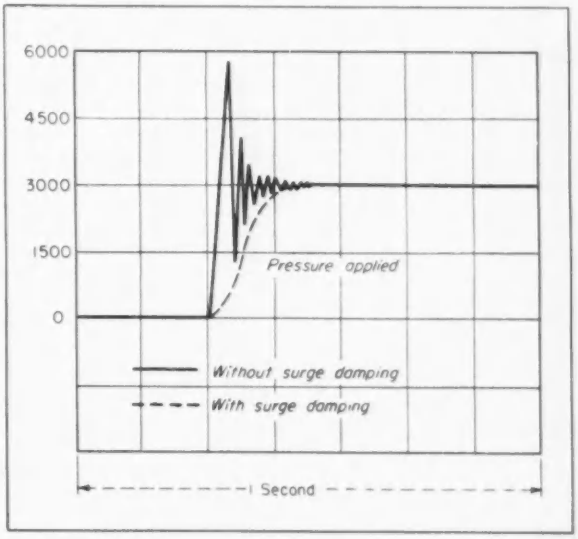
The aircraft model is smaller in overall size, and is threaded externally on each end to save weight. This valve is available in 4 tube sizes: $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, and $\frac{5}{8}$ inch. They are listed as E-106T-4, 6, 8, and 10, and may be used with systems operating at pressures up to 3,000 psi.

Parts numbered in the cross-section view above are:

(1) & (2) Two piece body; (3) Gasket; (4) Sleeve; (5) Plug; (6) Sleeve spool; (7) Pin fitted in spool; (8) Spring; (9) Reaction valve device; (10) Pin to hold (9); (11) Spring keeps needle from the seat in the spool; (12) & (13) Check valve poppet and spring; (14) Spring guide sleeve; (A) Orifice in head of device (9).

Recommended applications for the surge damping valve are: the port of four-way or reversing valves; in a cylinder circuit as an automatic decompression valve. It may also be used in any line leading from an accumulator or any part of a circuit that has a flow suddenly started after having been static or carrying a reverse flow. The chart at right shows an oscilloscope reading illustrating the effect of pressure suddenly released in the circuit. The valve is responsive to the pressures at the inlet and outlet connections so that changes and adjustments are unnecessary.





The Denison Engineering Co., Columbus 16, Ohio

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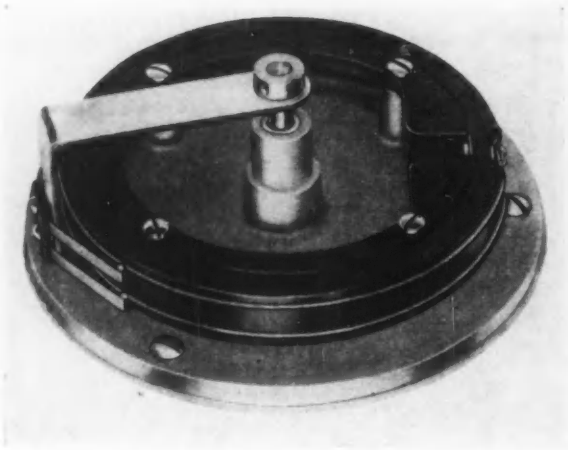
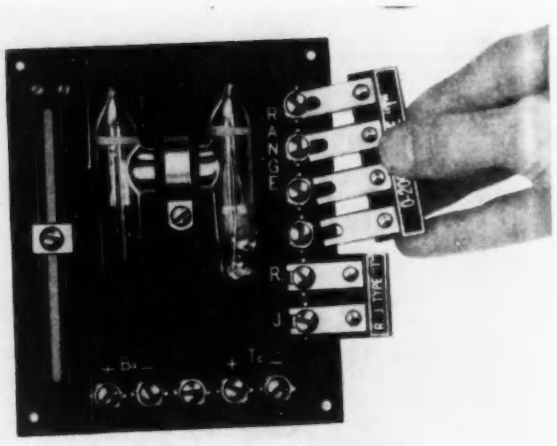




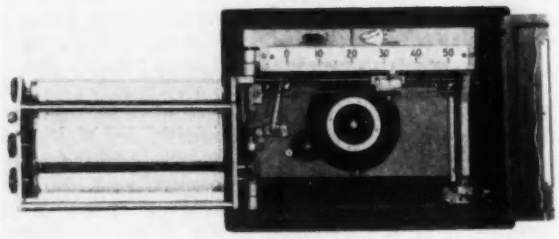
Simplified Recording Potentiometer

A new recorder of the null-balancing (potentiometer) type, claimed to set entirely new standards for both mechanical and electrical design simplicity and to give many operating advantages, has among its new features, a simplified chart frame which swings out full 180 deg on straight pivots with the chart always remaining in time sequence. When the frame is opened the pen lifts out automatically, reducing false line drawing and eliminating pen damage.

Changing chart speeds and changing ranges, also have been simplified. Chart speeds from inches per hour to feet per minute are available without gear changes. A screwdriver adjustment will give a selection of five different chart speeds that are doubled or quadrupled by changing one worm and gear assembly.

Changing ranges requires only substituting the desired range standard on the range panel and tightening by screw driver. There are no soldered connections to break, and no change is necessary in the universal slide wire. To change the reference junction compensation for another type of thermocouple, or to change the reference point (0.0 mvs) on a millivolt range, the compensation standard is replaced the same way. A slider on the range panel permits correction for the instrument electrical zero.

The amplifier uses two 12AV7 and two 12AX7 tubes that require no matching and are available at radio supply stores. Removal of the amplifier assembly for servicing or replacement simply requires pulling two plugs and removing two holding screws. The amplifier is provided with a



double pole, toggle type main power and motor switch.

The speed is approximately $1\frac{1}{2}$ sec to cross the chart on 60 cycle operation, and the accuracy within plus or minus $\frac{1}{4}$ percent with higher accuracies available. The recorder is furnished to measure and record temperature, a-c and d-c voltage, a-c and d-c current, resistance, speed ratio, power, frequency, hydrogen ion (ph), light intensity, or any other quantity that can be converted into electrical values.

The case of the recording potentiometer measures $15\frac{3}{4}$ x $11\frac{1}{2}$ x $14\frac{3}{4}$ in., and is adaptable to standard radio racks.

Weston Electric Instrument Corp., 617 Frelinghuysen Ave., Newark 5, N. J.

AN ELECTRICALLY LIGHTED MAGNIFIER for general industrial use is designed to speed detailed examination of all kinds of materials and products through self-contained direct illumination on the object. It comes equipped with either of two types of illuminator handles, one battery-powered, the other for connection with a 110 v power source. Either handle fits a reflector-type shade into which the magnifier snaps. Accessories furnished are a non-illuminating handle and a metal tripod, which multiply the uses of the magnifier. The instrument's lens system magnifies five times and is corrected to eliminate almost all spherical and chromatic aberration and distortion. It has a wide, flat field. Bausch & Lomb Optical Co., Rochester, N. Y.

OF LIGHT WEIGHT and very flexible, a new hose made with neoprene compounds and laminated nylon chafer duck, is being used for pressure and vacuum services. This wire reinforced hose has been designed for abrasive dust collection, heavy flexing and gravity feeds. Size is $1\frac{1}{2}$ to 24 in. ID. The American Ventilating Hose Co., 100 Park Ave., New York 17, N. Y.

CONTINUED ON PAGE 212

A Master DESIGN *Formula . . .*

Create an impression of high quality at first glance which will remain as a long-lasting sales asset after the day of delivery. This formula can often be applied *with*

MADISON-KIPP ZINC AND ALUMINUM DIE CASTINGS

The earmark of high quality is immediately apparent even on so simple a part as the die cast Oil Level Stick, here illustrated. Prospective buyers can quickly see and feel the difference.

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206 WAUBESA STREET, MADISON 10, WIS., U.S.A.

ANCIENS ATELIERS GASQUY, 31 Rue du Marais, Brussels, Belgium, sole agents for Belgium, Holland, France, and Switzerland.

WM. COULTHARD & CO. Ltd., Carlisle, England, sole agents for England, most European countries, India, Australia, and New Zealand.

- *Skilled in* DIE CASTING *Mechanics*
- *Experienced in* LUBRICATION *Engineering*
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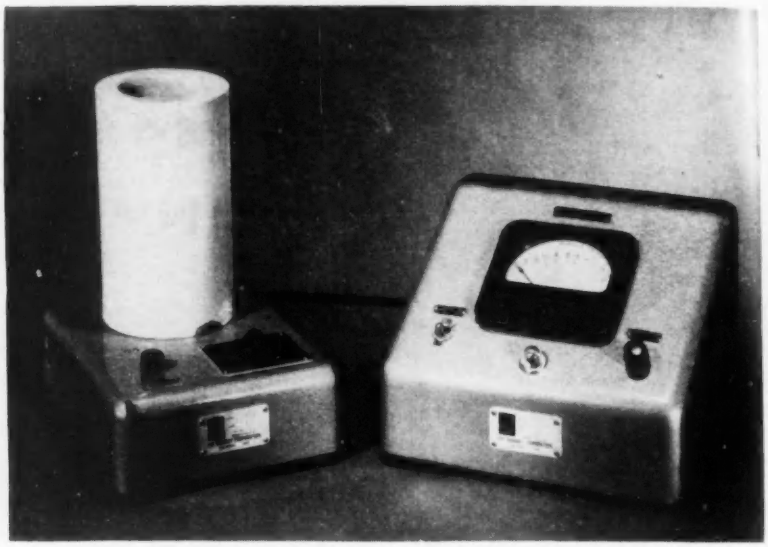
Radiation Detecting Instrument For Large Samples

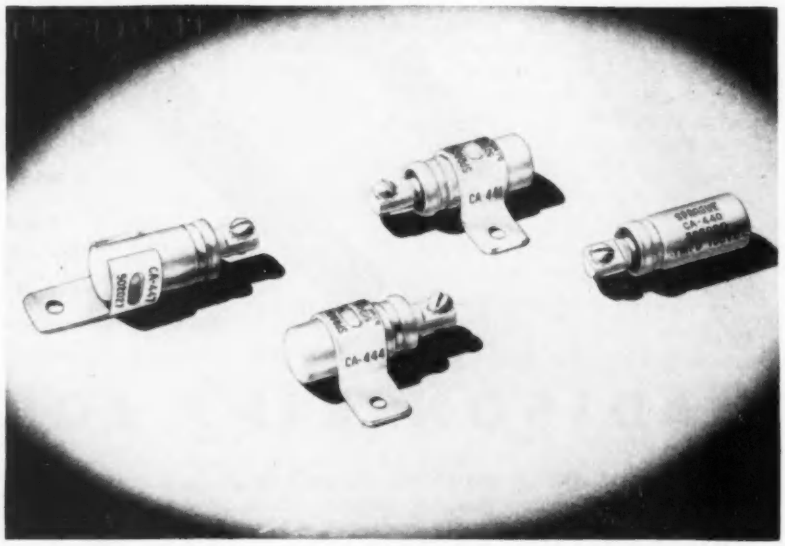


The radioactive-sensitive element in the new model AH-2 gammometer, as in all the instruments in the line, is a specially designed cell which converts radioactive energy directly into electrical energy. Use of this cell eliminates the need for a high voltage power supply, and only one vacuum tube is required. Samples may be placed in a well within the cell, minimizing geometry errors, and permitting the measurement of much larger quantities of activity than when slides must be prepared, resulting in maximum precision. The instrument eliminates the need for involved computations, as it is direct reading in microcuries.

The instrument is said to be well suited to applications where large liquid or solid samples must be used for accurate radiation measurement. The sample well in the cell of the gammometer measures $2\frac{3}{8}$ in. in diameter by 5 in. in depth. As it will accommodate samples having volumes up to 200 milliliters, 1 microcurie range can be used to measure concentrations of activity down to 5×10^{-10} curies per milliliter. Ranges of the instrument are 1, 10, 100, and 1000 microcuries full scale. A calibration curve giving the relationship between source distance from the cell and instrument response is used with each instrument to aid in the measurement of radiation from an external source. The instrument is available calibrated in terms of radium (standard), cobalt-60, or iodine-131. Precision is better than plus-or-minus 1 percent of full scale, and accuracy is plus-or-minus 2, 2, 3 percent of full scale respectively. For measurement of ambient field intensity the gammometer is available calibrated in milliroentgen per hour.

Ohmart Corp., 2347 *Ferguson Road, Cincinnati* 38, *Ohio*

Low-Voltage Vehicular Bypass Capacitors



A new line of hermetically-sealed corrosion-resistant capacitors for radio-interference suppression on the low-voltage electrical systems of military vehicles, and portable gasoline-driven power plants, has been designed to meet Army Specifications 71-1667 and Ordnance Drawing DQBX1. Known as type 131 J, these metal-encased capacitors will withstand shock and vibration as well as atmospheric moisture and salt spray. Capacitance values of 0.01, 0.1, 1.25, and 0.5 mf are available with either right- or left-hand mounting brackets, end brackets or without brackets.

Extended foil (non-inductive) capacitor sections and a short, direct lead between the ungrounded foil and its heavy terminal assure minimum r-f impedance and maximum bypassing efficiency. Terminals are fitted with Sems fastener screws with captive toothed-lockwashers for connection.

Sprague Electric Co., 195 *Marshall St., North Adams, Mass.*

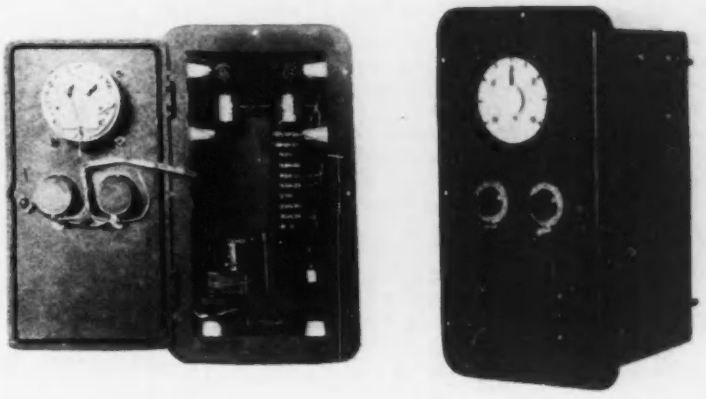
CONTINUED ON PAGE 215

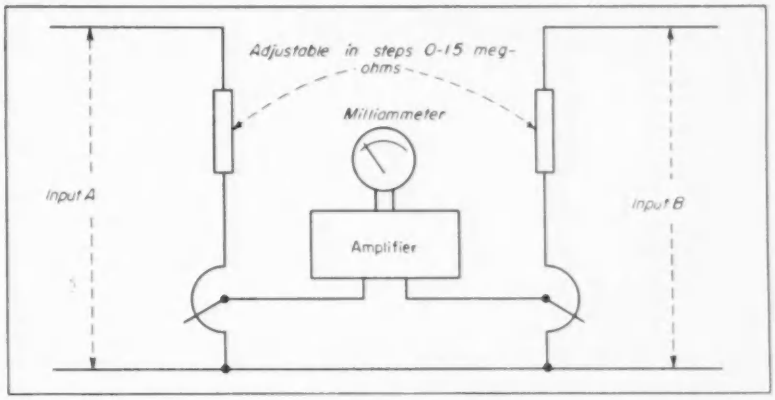
Wide Range Differential Voltage Indicator

A new indicator, designed to measure differential voltage, as well as amperage, speed, pressure, and other quantities which can be converted to voltage, is basically a high-resistance precision voltmeter containing an electronic amplifier, and features a self-balancing circuit with a high degree of stability and freedom from drift. It is capable of measuring a 0.001-30 v differential of two input voltages ranging from 1 to 400 v, providing they do not differ by more than 300:1. The instrument can be set to indicate full scale for voltages as small as 0.022 volts. The scale can be marked in volts, amps, or feet per minute.

Used with standard accessories, such as a recorder, indicating instrument, or alarm relay, the differential voltage indicator will record deviations at a point remote from the installation.

In operation the two input voltages, whose difference is to be measured, are connected across to precision, resistance, voltage dividers. As these voltage dividing resistances are ordinarily very large, the current drain on the voltage source is small. A small portion of the input voltage is taken from the voltage dividers and balanced against a similar voltage from the other voltage divider. The difference between these two small voltages is amplified and read on a milliameter. When comparing two voltages which are normally equal, the two voltage dividers are adjusted to the same resistance value. However, when comparing two input voltages that are not normally equal, the two dividers are adjusted to unequal ratios.





General Electric Co., 1 River Road, Schenectady, N. Y.

New Multi-Turn Slide Wire Potentiometer

Designed for applications requiring high resolution with angular shaft displacement up to 3600 deg., the new potentiometer known as the spiralpot may be used on computers, servo-control, and similar devices. The electrical output is exactly proportional to the angular shaft position with the brush traversing the length of a resistance wire as the shaft is rotated.

The multi-turn slide wire potentiometer has such features as: small size (1.61 in. long x 1.75 in. dia.); low noise level; unlimited (zero increment) resolution and low torque; plus higher resistance ranges than are usually found in slide wire potentiometers. It also has the ability to withstand 50 G steady state acceleration along any axes; positive mechanical stops that will hold up to 500 oz.-in. torque; a shaft mounted in ball bearings; and close concentricity between the shaft and the mounting surface with a synchro-type mounting.

The new spiralpot unit is available in a range of five standard resistance values from 500 ohms to 2500 ohms in 500 ohm increments. Good linearity is possible. It can meet specifications during 10 G sinusoidal vibration from 10 to 100 cps in all axes and 10 G in selected axes up to 200 cps, and functions mechanically in temperatures from —55 to +71 C. Less than 2 oz.-in. of torque is required, and it can dissipate up to 2 watts at +71 C. Weighing only 4 oz., the unit has minimum backlash and is said to last over a million revolutions at 200 rpm.

G. M. Giannini & Co., Inc., Pasadena, Calif.

CONTINUED ON PAGE 216

Radiation Detecting Instrument For Large Samples

The radioactive-sensitive element in the new model AH-2 gammometer, as in all the instruments in the line, is a specially designed cell which converts radioactive energy directly into electrical energy. Use of this cell eliminates the need for a high voltage power supply, and only one vacuum tube is required. Samples may be placed in a well within the cell, minimizing geometry errors, and permitting the measurement of much larger quantities of activity than when slides must be prepared, resulting in maximum precision. The instrument eliminates the need for involved computations, as it is direct reading in microcuries.

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Low-Voltage Vel

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Sprague Electric Co., 195 Marshall St., North Adams, Mass.

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Wide Range Differential Voltage Indicator

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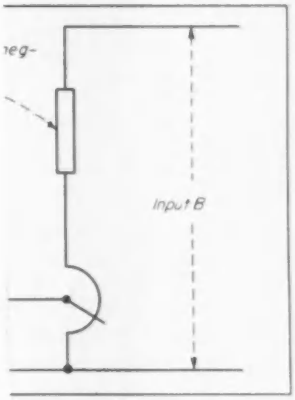

River Road, Schenectady, N. Y.

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SSING

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The new spiralpot unit is available in a range of five standard resistance values from 500 ohms to 2500 ohms

G. M. Giannini & Co., Inc., Pasadena, Calif.

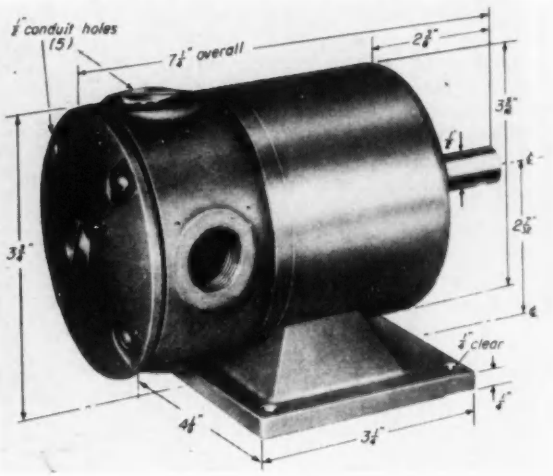
CONTINUED ON PAGE 216

Direction And Zero Indicating Contactor

A new direction and zero indicating contactor operates at speeds as low as 4 rpm and over 5000 rpm, in temperatures between —20F and+250F. Ratings are from ½ amp to 10 amp. at 110 V. a-c, and construction is all metal. A small compact unit, it can be mounted in any position. It is a self-lubricating, hydraulically driven mechanism, with magnetically actuated contacts.

Applications include: indication of shaft rotation and direction of rotation; prevention of stationary controls from operating while parts are revolving; controls on conveyors; to interlock motor starters for protection against back spin; to prevent reverse power from being applied to a motor until a complete stop is made; used in conjunction with counting devices to indicate the number of stops and starts of equipment; and is used as a time study device for running and down time on belt or clutch driven devices. It also may be used as a plugging switch. Adjustable models are available for cut-in, and cut-out speeds to 100 rpm.

Winterburn Mfg. Co., P. O. Box 386, Putnam, Conn.



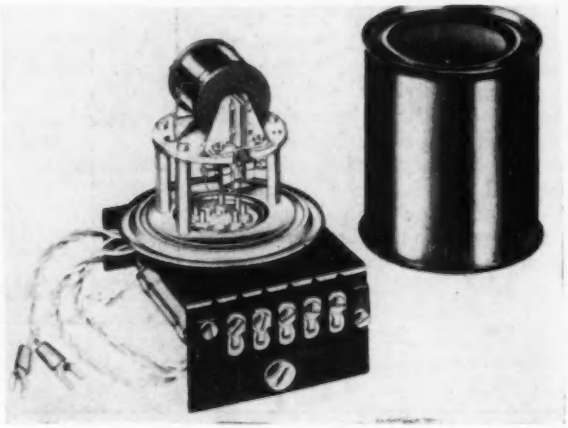
High Sensitivity Synchronous Inverter

A synchronous inverter, having a sensitivity of 0.05 microvolts and a dissymmetry of less than ½ of 1 percent is capable of converting low-power d-c signals, as low as 0.05 microvolts, to alternating voltages that can be amplified and applied to electronic, electrical and servo systems.

Called the syncroverter switch, it will operate at any frequency from zero to 3500 cycles, and is designed for precision use in electronic computors, instruments, gun directors, null detectors, and other similar missiles. Operation and length of life are not affected by vibration.

Errors due to thermal emf are eliminated by the use of two single-pole double-throw contacts. The contact-carrying armatures are of such low mass that their mechanical response is said to be almost instantaneous. The inverter is free from resonance effects, and is hermetically sealed

The Bristol Company, Waterbury 20, Conn.



Non-Leaking, Self-Closing Push Valves

A new self-closing push valve is used in gas and air lines where manual control of an intermittent flow is required, and where there must be no leakage through the valve or around the valve stem. Typical applications include use with hydrostatic gages and other instruments requiring a manually-controlled blast of air; use with single-and multiple-pressure test stands; blowing out or purging of gas or air lines; and use with processing operations needing an occasional shot of gas or air.

The valve is opened by pressing a knob on the valve stem, and closes automatically when the knob is released. It has no compression packing and requires no adjustment, being sealed by neoprene 0-rings. On a test, the valve showed no leakage after 1,000,000 cycles of operation.

This valve is available in two styles: model PV, mounting on panels of any thickness up to $\frac{7}{16}$ in., and model LV for the in-the-line mounting. Inlet and outlet are tapped for ¼ in. pipe, and direction of flow is shown by an arrow. Discharge rate is 25 to 30 cubic feet per minute at a pressure drop of 100 psi. Overall height of the valve is 3 in.; thickness is one in.; length (line of flow) is 1¾ inches. It may be used at any pressure up to 150 psi.

King Engineering Corp., Ann Arbor, Mich.

CONTINUED ON PAGE 218

Draftsmen work better, faster with this machine...

PHOTOS BY COURTESY OF THE UNIVERSAL DRAFTING MACHINE CORPORATION

By holding spindles absolutely rigid and keeping motion friction-free, Fafnir Ball Bearings contribute much to the vernier accuracy and effortless action of the Universal "Boardmaster". The ultimate results are more accurate sketches, layouts or detailing and "on the nose" template work in faster time . . . so important when good engineers and draftsmen are scarce.

At three pivot points, pairs of extra-light, compact single row, Fafnir Ball Bearings give finger touch ease of movement without a trace of play. At the "centralized control unit", a large diameter Fafnir Bearing is used together with paired, preloaded and pre-lubricated Fafnirs. Six of the seven Fafnir Bearings used are Plya-Seal Type, which prevent lubricant leakage, keep out contaminants, and are lubricated for life.

The faculty for providing custom-made types of bearings out of stock . . . from the most complete line in America . . . makes Fafnir the first source consulted by leading manufacturers. Maybe you can solve bearing problems this easy way. The Fafnir Bearing Company, New Britain, Conn.

Standard Radial Bearings

Wide Inner Ring Ball Bearings with Mechani-Seals

Plya-Seal Type Bearings

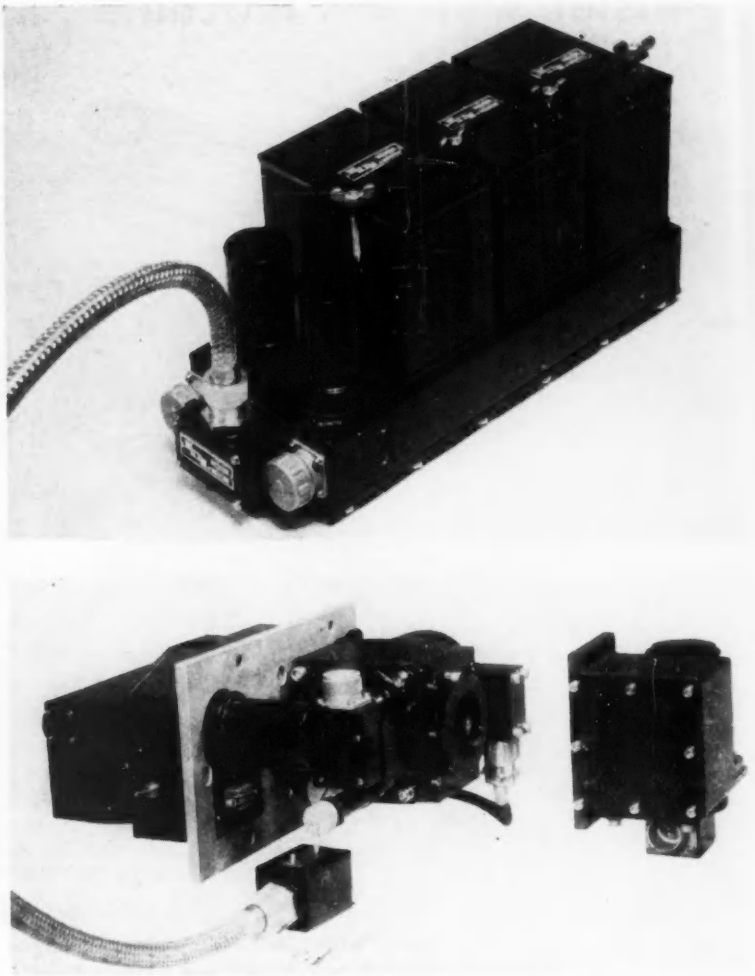
Automatic Process Control by Light Measurement

Adaptable to all types of industry, an instrument known as a precision light-comparator is being used to improve methods of automatic processing and control. Built around a photomultiplier, a flicker photometer optical system, and an electronic system, the instrument will operate continuously for thousands of hours without zero or sensitivity drift.

Known as colorede, the unit is designed as an assembly of sealed building block units, arranged to permit various combinations to fit particular measuring purposes. In most applications, the electronic unit, the photocell unit, the flicker unit, and the servo-slit unit are used in standard form. The beam-splitter and illuminator units may be one of several standard arrangements, or assemblies designed for specific uses.

The instrument may be operated as a direct signal device, providing a d-c voltage of up to 1.0 v for one percent full scale relative brightness difference between a sample and a standard. An alternative service is the use of the servo driven slit as a direct quantitative measure of brightness difference, with either mechanical actuation or electrical signal transmission operated from an output shaft geared to the servo drive. The d-c signal may be used for the operation of standard recorders, controlling, and servo devices. The servo operated shaft drive may be used to drive computer systems for complex control functions.

Typical applications include: the recording or process control through the use of chemical color indicators, or the control or indication of the color of liquid or solid products; the measurement and control of thickness of applied coatings; automatic shading or control of dyeing in the textile industry; and in printing; photography; ceramics and other industries.



Shown in the illustration below left is the main unit, consisting of the beam splitter unit, the slit system, the flicker unit, the photocell unit, the mounting place, and the data assembly. Slightly to the right is the illuminator unit. The electronic assembly is shown in the illustration at top.

Instrument Development Labs., 163 Highland Ave., Needham Heights 94, Mass.

Positive Indication of Air Line Moisture

An air line moisture indicator for use in air or gas lines gives a positive visual indication of the presence or absence of moisture in the line.

This unit consists of a pyrex glass cylinder filled with moisture-sensitive blue granules, and has end plates tapped for $\frac{1}{4}$ in. pipe. In operation, it is placed in the line between the air supply and the point at which the air is used. The granules stay blue as long as the air leaving the indicator is dry, and turn pink when it contains moisture or water vapor.

Four tie rods protect the cylinder against damage and permit disassembly for recharging with dry granules. All units with the glass cylinder are tested at 100 psi pressure. Moisture indicators with clear plastic cylinders can be furnished for higher pressures. Overall dimensions are 5 in. long x $2\frac{5}{16}$ in. square.

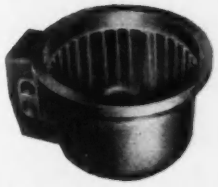
King Engineering Corp., Ann Arbor, Mich.

CONTINUED ON PAGE 220

creative castings

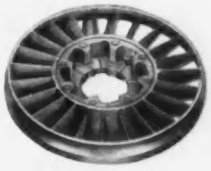
Motor End Frames

Gyrol Fluid Coupling



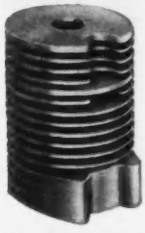
Garbage Disposer Housing

Aircraft Piston



Torque Converter

Fuel Pump Body



Carbon Pile Regulator

Steel-Belted Piston

Alternator Housing

Diesel Permanent Mold Piston

Wing Actuator

Air Connector

Launching Barrel for Bazooka

For many years the foundry of Thompson's Light Metals Division quietly cast thousands and thousands of hard-to-make precision parts in light alloys of aluminum and magnesium for customers in the automotive and aircraft fields.

Then word got around in other industries that Thompson had the experience and facilities to cast light-weight, strong, heat-resisting alloy parts in permanent molds and high pressure dies—which eliminated the weight problems of ferrous counterparts. One by one manufacturers of widely different products came to Thompson for help and advice when they learned that the close tolerances achieved by Thompson cut machining and finishing costs.

Today, our capacity is channeled to top-rated jobs. We're building additional facilities as fast as possible and, in the meantime, Thompson services, as always, are at your command. Our entire staff of creative engineers is ready to help you plan new parts or re-design old ones for the future.

YOU CAN COUNT ON . . .

Thompson Products, Inc.

2269 Ashland Road • Cleveland 3, Ohio

LIGHT METALS DIVISION

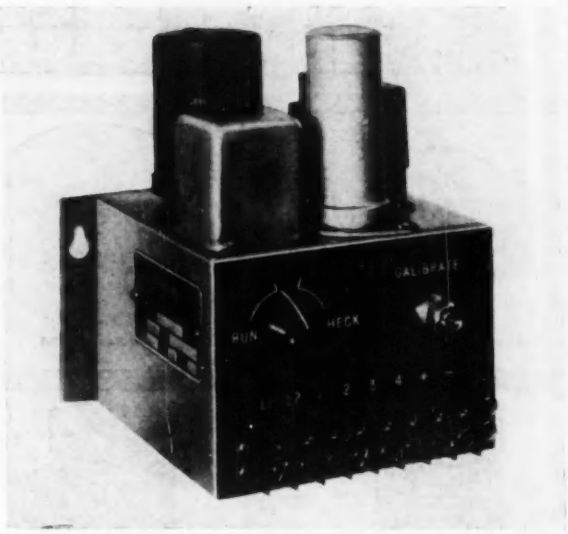
Demodulators For Transducer-Servo Systems

Three new demodulators have been designed for rectifying an a-c signal, generated by a transmitter for pressure, flow, thickness, weight, or displacement into a d-c signal that may be fed into a D'Arsonval type d-c meter or potentiometer type instrument of the indicating or recording variety.

The 6101A and the 6101B type demodulators are designed to operate into any D'Arsonval type meter of the proper type and range. This unit has a single electronic tube rectifying circuit designed for continuous service. The model 6101C demodulator, shown in the illustration, is designed to operate into any existing potentiometer type recording or indicating instrument. This type incorporates a chopper circuit for changing the a-c input signal to the d-c output signal.

The types 6101A and 6101B demodulators have an output that is linear to within ± 2 percent of full scale range. When it is necessary to obtain greater accuracy, the meter used with the demodulator can be calibrated to the output of the demodulator, and the accuracy obtained will be determined by the accuracy of the meter used. The output of the demodulator varies slightly with changes of line voltage. This effect can be reduced by placing a constant voltage transformer in the line supply.

The type 6101C vibrator-type will reproduce an output that is directly proportional to the input signal. The accuracy of this unit when used with a differential transformer, will depend on the linearity of the transformers,



resulting in an accurate measuring system. The meters are only 4 in. sq., designed for flush mounting and displacement for full scale travel.

Automatic Temperature Control Co., Inc., 5200 Pulaski Ave., Philadelphia 44, Pa.

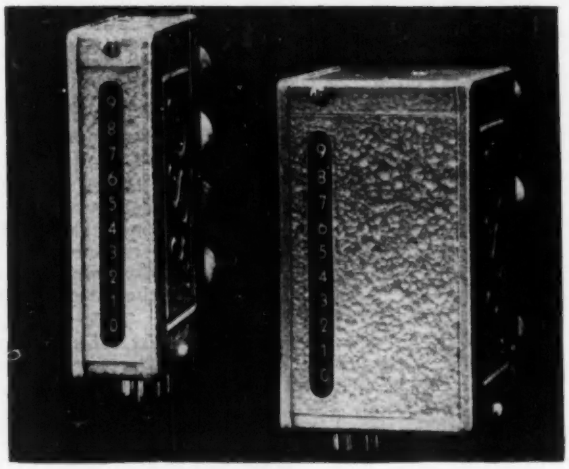
Direct Reading, Plug-In Counters

These decimal counting units are direct-reading, electronic counters capable of operating at speeds up to 1,000,000 counts per sec and resolving paired pulses separated by as little as 0.8 microseconds. Each counter is a plug-in unit designed for easy replacement, and simplification of maintenance problems in high-speed counting equipment. These units of the same model designation are completely interchangeable.

The decimal counting unit counts from 0 to 9 and presents an illuminated numerical reading on the front panel. No interpolation is necessary. The tenth pulse resets the counter to 0 and simultaneously generates one pulse, which may be applied to the input of a following counter or other device. Reset to 0 of one or more units is accomplished by momentarily opening the grid return circuit. The counters may be connected in cascade indefinitely to create an electronic counter or scaler having any desired number of decimal places.

Standard plug-in mounting permits removal of the entire unit for inspection. The models 700A and 705A use the octal plug and the models 706A and 707A the 11-pin plug. With the exception of the model 707A, the components of all the counters are mounted in a plastic molding.

In both the model 700A and the model 705A, four binaries are connected in cascade, making a scale-of-sixteen, which is permuted to a scale-of-ten by two resistor-capacitor "feedback" networks. Maximum counting rate of these models are 40,000 cps and 100,000 cps respectively.



Both of the models 706A and 707A consist of a four-stage binary scale-of-sixteen that is permuted to a scale-of-ten. Permutation is obtained by adding 2 counts and subtracting 8 counts through a system of diodes used as interstage couplings and clamps. Maximum counting range of these models are 350,000 and 1,000,000 cps respectively.

Berkeley Scientific Corp., 2200 Wright Ave., Richmond, Calif.

CONTINUED ON PAGE 222

4 shortcuts to SURER finishing results!

How a finish—or finishing system—adapts itself to the practical requirements of commercial production is just as important as how it performs on the finished product.

This is one of the important advantages buyers get with such production-proved Sherwin-Williams finishes as those listed here. They not only better fit the specific needs of the product to be finished, but of the production line as well.

If your production involves the finishing of furniture or wood products of any type, it will pay you to investigate the "shortcuts to surer results"—both in methods and materials—described in these new Sherwin-Williams brochures. Write for those applicable to your problems. The Sherwin-Williams Co., General Industrial Division, Cleveland 1, Ohio.

THE SHERWIN-WILLIAMS CO.
General Industrial Division • Cleveland 1, Ohio

Please send Brochures checked below.

☐ **K-101—KEMVAR**—A new advance in high resistance, heat-converting finishes for fine furniture.

☐ **H-102—HEETCLAD LACQUERS**—Materials and systems for use with modern, cost-cutting hot spray methods.

☐ **T-103—TV LACQUERS**—Extra-flexible, tough, mar-resistant materials in service on leading makes of TV cabinets.

☐ **H-104—HOMOCLAD**—A totally unique sealer and system with highest properties of bonding and moisture sealing.

NAME_____

COMPANY_____

ADDRESS_____

SHERWIN-WILLIAMS
INDUSTRIAL FINISHES

Sensitive Magnetic Powder Clutch

A magnetic powder clutch, formerly used only in aircraft, is now available for commercial and industrial use, and has been application-tested for use on dynamotors, generators, marine drives, reversing drives, servomotors, and variable speed drives.

The powder clutch control medium is an iron powdered mixture contained within the air-gap space between two magnetic surfaces. The electro-magnet with its exciting coil constitutes the driving member, while the driven member consists of a low-inertia drag cup concentrically located in the air-gap. As the clutch coils become energized, a magnetic field is established through the air-gap; the divided iron particles become magnetized, bind together and exert a drag on the cup in the direction of motion of the driving member. The drag is proportional to the applied excitation, but is independent of the relative speed of the driving and driven members.

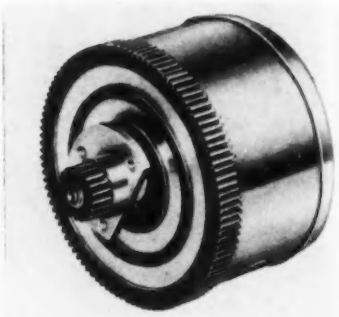
Two such counterrotating clutches, with their drag cups geared to a common output shaft, produce a torque proportional to the differential excitation of the two clutches. The direction of the torque is dependent on which clutch has the larger excitation.

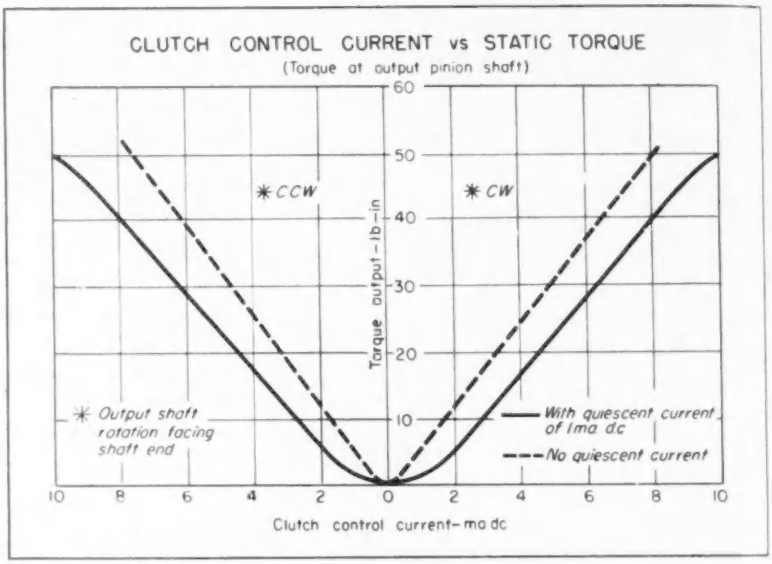
Clutches of this type have been built having torque-to-inertia ratios as high as 500,000 radians/sec.^{2}, and power ratings of 25 in.-lb at 2,000 rpm for a weight of one pound.

The clutch shown in the illustration is used in servo actuator systems for aircraft and has overall dimensons of 2.104 in. x 2.229 in. in diameter. At present the clutches are produced in the 1, 2 and 2½ in. size.

Since the powdered iron is not mixed with any liquid, there is no problem of leakage or of poor starting characteristics at low temperatures. Also, the clutch may be operated at temperatures up to 250 F.

Lear Inc., 11916 *W. Pico Blvd., Los Angeles 64, Calif.*





New Accelerator For Testing Larger Components

An 8 ft. dia. model C g-Accelerator has been added to a line of testing devices and is similar in arrangement and operation to the smaller 56 in. dia. model B. The unit has optical, pneumatic, and electrical systems combined for testing aircraft and guided missile components of a larger size than has been possible.

The object to be tested is secured to either of the two mounting platforms on the rotating arm, and the arm is balanced by securing a similar mass on the opposite end. Electrical leads and air connections are carried to the mounting platform through slip rings and a rotary air gland. The test object can be seen as if stationary, regardless of rotational speed, through a telescopic optical system, permitting close observation of the part.

Similar to the smaller 56 in. diameter models, an indicating tachometer and a precision timer, combined with a solenoid-operated rpm counter, measured speed with sufficient accuracy to determine G-loadings with an error of less than 0.1 percent, dependent upon the time interval chosen.

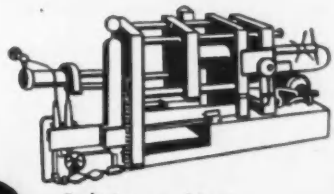
All controls terminate at the operating console which contains a built-in conversion chart for rpm, radius of gyration and acceleration.

With the object mounted in the center of the 24 in. square platform, precisely controlled speeds, adjustable from 5 to 280 rpm and developing normal acceleration forces up to 75 G, are readily attainable. An important feature for routine production testing is the ability of the machine to return to a preset speed by use of the starting switch only. Time to reach full speed from standstill is 30 seconds.

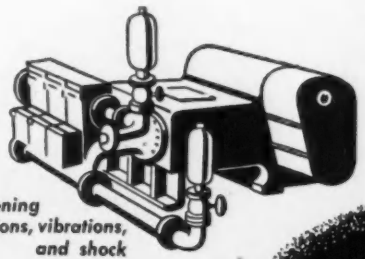
The maxiumum capacity of the test object is an 18 x 18 x 24 in. volume up to 100 lbs. The maximum acceleration force is limited to 2000 G-lbs; 100 lbs at 20 G—40 lbs at 50 G.

Genisco, Inc., 2233 *Federal Ave., Los Angeles 64, Calif.*

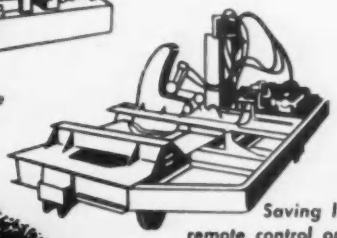
CONTINUED ON PAGE 224



Reducing machine floor space and operating cost



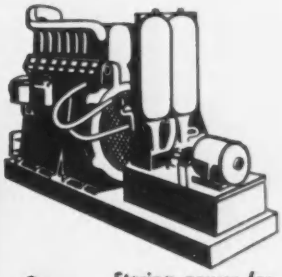
Dampening pulsations, vibrations, and shock



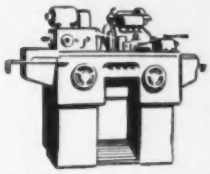
Saving labor by remote control operation

Many PROBLEMS One SOLUTION

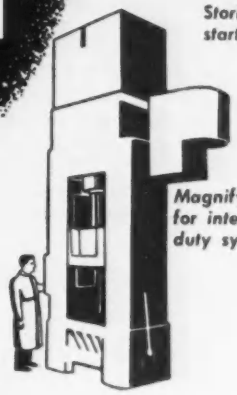
Holding work securely for long periods



Storing power for starting engines



Reducing size, cost, and power requirements of machinery



Magnifying power for intermittent duty systems

Furnishing emergency power when pumps fail

Above are but a few of the hundreds of valuable functions performed by Greer Accumulators. Greer Bulletin 301 is packed with data, diagrams, and illustrations showing how Greer Accumulators have increased the efficiency and dependability and reduced the cost of various types of power-driven equipment. Send now for your free copy.

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GREER
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Light, Compact Motor Operated Gate Valve

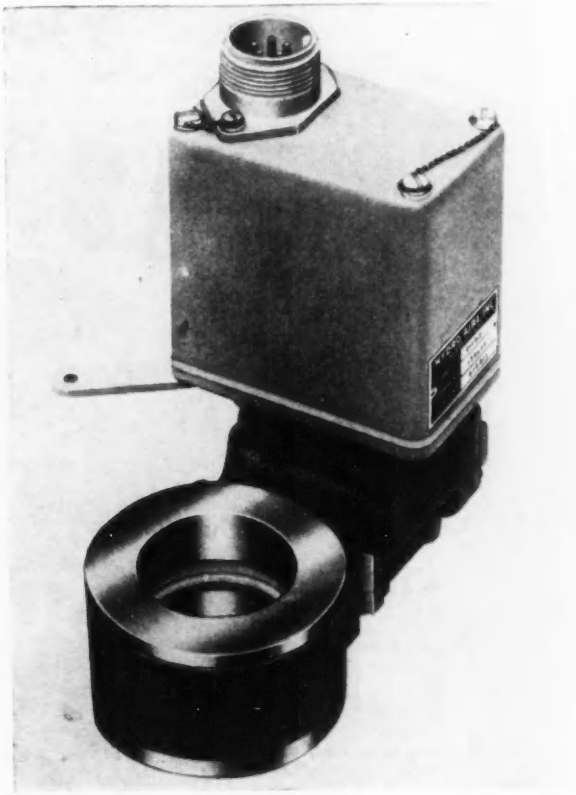
A new motor operated gate valve is said to be one of the lightest and most compact ever developed. A new method of manual over-ride, as well as a complete elimination of rubber or synthetic rubber, are also important features in this valve. Designed for aircraft use, the manufacturer claims that the new valve will have applications in other industries.

The elmination of rubber and synthetic rubber was accomplished through the use of teflon. This material was used for its high fuel resistance. All seals are spring loaded and confined, where necessary.

One of the features in this valve is its limit switching arrangement which makes it impossible for the valve to stop in mid-position, eliminating many possible operating failures. It has no limit switch adjustment, and the switching operation is said to be foolproof. This design also makes possible a manual override which completely bypasses the motor and gear train, and requires no more operating torque than a manually operated valve of equal size and equal operating pressure.

The valve operates with all aircraft fuel, engine oil, hydraulic oil, alcohol, water, air, and gas. It has an operating time of one second maximum and operates at a voltage of 18- 30 d-c. Its proof pressure is 200 psi. It works at -65 to 165F, and at a pressure of 0 to 65 psi. The flow can be in either direction.

Over-all dimensions of the new unit are 5 in. in height and $4\frac{3}{8}$ in. in length. The thickness is $1\frac{5}{16}$ inches.



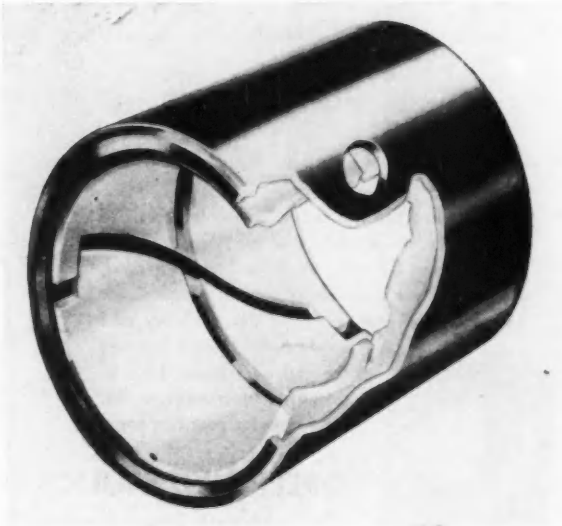
Hydro-Aire, Inc., Burbank, Calif.

Nylon Liner In Bearing Is Replaceable

A new type of nylon-lined bearing consists of a thin, drawn steel outer sleeve and a free floating liner of FM 10001 nylon. They are called standward thinwall nylined bearings, and are available in ten sizes ranging from $\frac{1}{4}$ to $1\frac{1}{4}$ in. I.D.

The thinwall nylined bearings were developed to provide bearings of resilient material which resist poundout, decrease friction, permit dry operation, damp mechanical vibration and minimize abrasion failures. They are corrosion resistant and can be operated submerged in most liquids. These light weight bearings are suitable for close fits and are said to give a longer life with less maintenance in most applications than the ordinary molded or machined nylon bearings that have limitations due to the clearances required to allow for expansion.

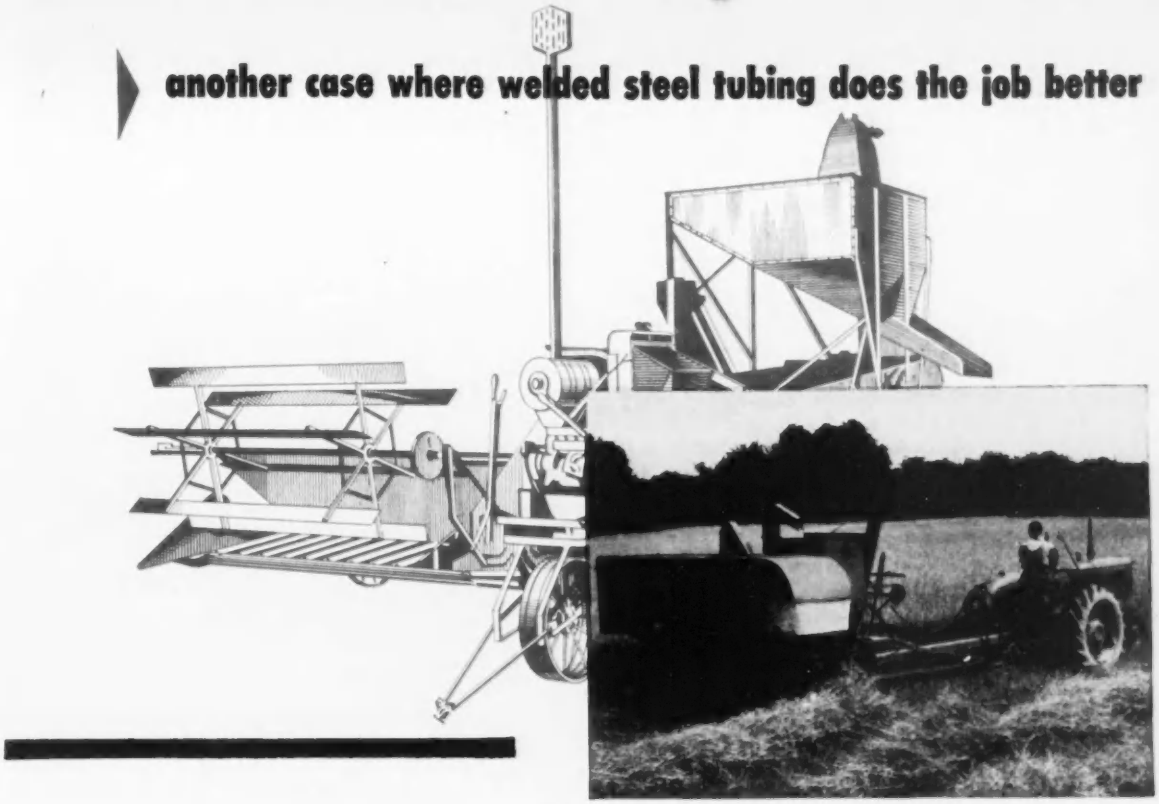
The nylon liner, which is a replaceable bearing surface, has a spiral compensation gap which serves a dual purpose. It compensates for dimensional changes in the circumference due to expansion and contraction which would otherwise cause fluctuations in the bore diameter. In applications where lubrication is required, this gap also serves to distribute lubricant in an axial direction as it connects with the center circumferential lubrication slot which receives lubricant through the hole in the outer sleeve.



Thomson Industries, Inc., Manhasset, N. Y.

CONTINUED ON PAGE 226

another case where welded steel tubing does the job better



ELECTRUNITE Steel Tubing made this farm equipment better at lower cost . . .

it can do the same for you . . .

Unnecessary dead weight was lopped off in hundred-pound chunks without reducing strength when a leading farm implement manufacturer designed his line to use Republic ELECTRUNITE Steel Tubing at every possible point.

Strength and shock resistance were increased because Republic ELECTRUNITE Steel Tubing provided maximum strength per pound of metal over ordinary conventional shapes. Troublesome torsion and weaving of implements on rough ground was cut drastically . . . useful life of the implements was greatly lengthened, and maintenance reduced.

Does this give you some ideas about *your* product . . . whatever it may be? Republic ELECTRUNITE Steel Tubing can keep your product strong yet make it lighter, make it better at lower cost, more attractive to the man who uses it . . . and who buys it. We'd like to tell you our ideas.

Republic ELECTRUNITE TUBING

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50th ANNIVERSARY 1902 1952 STEEL and TUBES DIVISION ELECTRUNITE TUBING

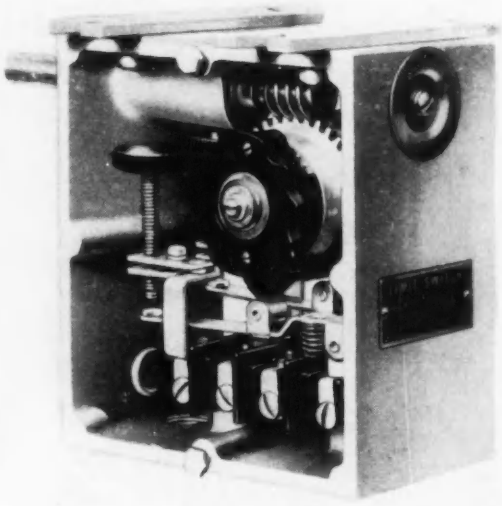
***FREE BOOKLET**—Write for Booklet SPD-52...contains data and case histories on ELECTRUNITE Tubing applications.*

Rotating Limit Switch For Rotating Parts

A rotating limit switch to limit the travel of rotating parts of machines or equipment such as electrically operated doors, hoists and valves, co-ordinates reversing operations with the rotation of the motor shaft, or other operating shaft, to break contact, the timing of which is governed by a preset number of shaft revolutions.

The mechanism consists of two separate switching units each operated by a cam. These cams engage with contact arms to open or close a circuit for each end of travel, and are mounted on either side of a die-cast gear which is driven by a worm gear attached to a shaft operating through the switch case. The switch may be adjusted to open either of the two normally closed contacts with the rotation of the operating shaft by changing the relative positions of the cams. One of the cams is spring-loaded and equipped with an indexing pin which snaps into any one of 32 holes in the gear body on which it is mounted. Fine adjustment is then made by the contact adjustment-screw, after the positions of the cams has been set, so that the switch will cut off at the desired instant. The overall size of the case including the brackets is $6\frac{1}{8}$ in. high, $4\frac{3}{4}$ in. deep, and $5\frac{3}{8}$ in. wide.

The switch is rated at 3 amp; 110V a-c, or 1.5 amp. 22V a-c; d-c with a 0.5 mfd condenser: 0.2 amp 115V d-c, 0.1 amp 230V d-c. Max turn of the drive shaft is 34, min. 2.



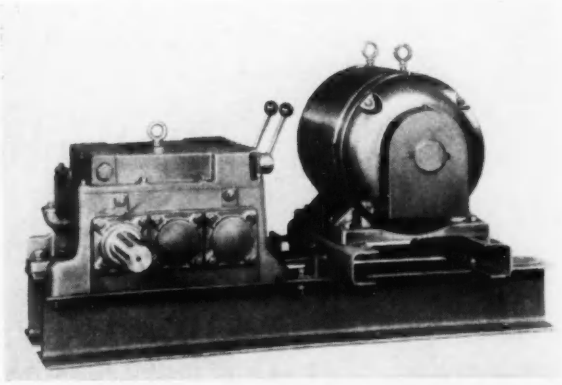
Furnas Electric Co., 1050 McKee Street, Batavia, Ill.

Multi-Speed Transmission for Heavy Applications

Three new models of multi-speed power units for heavier horsepower applications, models 2004, 3004 and 5004 transmissions, are available in ratings up to 60 H.P., making them adaptable to a wide range of heavier applications. The units may be used wherever it is necessary to vary the turning speed of electrically-driven equipment or machinery. Many installations are in connection with internal-combustion engines where it is advantageous to run the engine at a constant speed and vary the output speed with the multi-speed transmission.

While all transmissions are available in four speeds, with a selection of different speed ratios, some models can be supplied with six and nine speeds.

A feature of the transmission is the availability of two different type mounting brackets. The type RMB is a vertical mounted arrangement with the motor mounted on a hinged plate directly over the transmission. Type H-Beam mounting is the motor mounted in front of or behind the transmission. The motor slide rails on the H-Beam have both lateral and longitudinal adjustment to accommodate different motor frames and belt take up. Output shaft can be left or right, forward or rear. For further information on these and other types of transmissions write to the manufacturer.



Turner Machinery Co., 3415 Terrace Street, Kansas City 8, Mo.

A NEW PUSH BUTTON SWITCH, added to the line of waterproofed switches, opens and closes electrical circuits underwater, and is said to function perfectly from —65 F to 165 F, and withstand salt spray, shock and vibration. The switch has a continuous rating of 10 amp at 15 v d-c, 30 v d-c, or 125 v a-c. It is a single throw, one circuit switch, furnished either normally "open" or normally "closed." The switch body is encased in a molded rubber compound with waterproof lead wires vulcanized into the rubber case. Overall length of the switch is approximately 2 in., length behind the mounting panel is approximately 1 inch. Largest body diameter is 15/16 inch. Riverside Mfg. & Electrical Supply Co., 10228 Michigan Ave., Dearborn, Mich.

CONTINUED ON PAGE 228

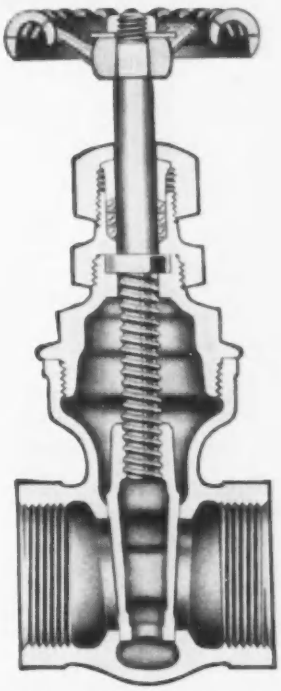
For quicker answers to piping problems

Go to your CRANE Catalog

Crane offers the world's most complete line of piping equipment. But suppose your design requires a certain brass gate valve of unusual ruggedness. How would you find it?

Simply reach for your Crane Catalog and turn to the listing of brass gate valves in the index—pages 13 to 21. A quick rundown of service recommendations shows that No. 437 on page 17 is the valve you're after. And right there are all the facts you need—sizes, dimensions, pressure and temperature ratings, plus complete design, material and construction details.

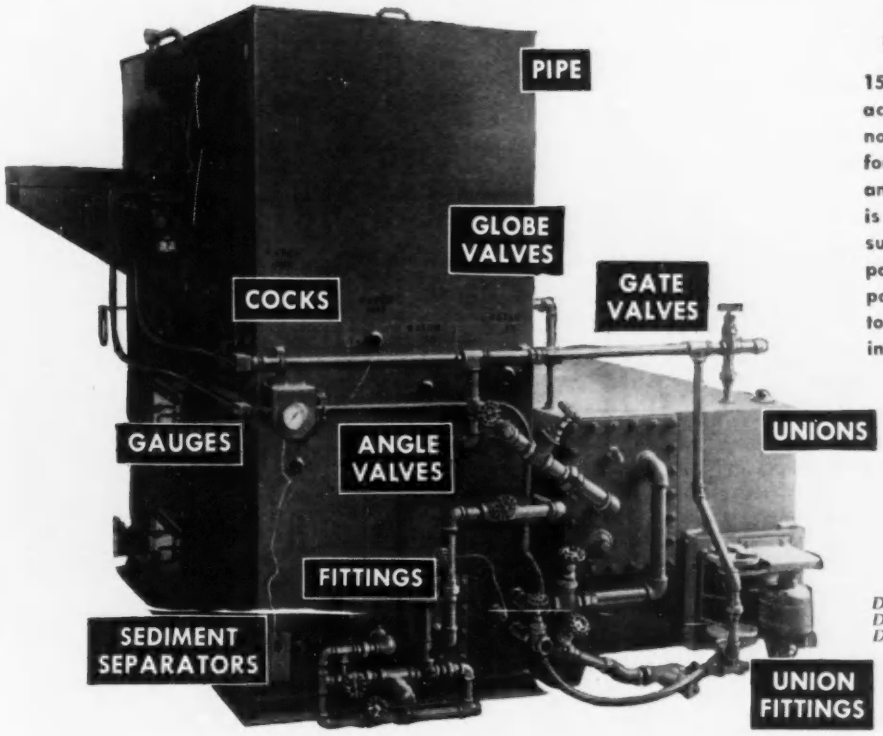
Yes, your Crane Catalog is a real time-saver when writing specs. But, more important, when you specify Crane piping equipment, you specify recognized quality that pays off in terms of customer acceptance and satisfaction through the years.



UNUSUALLY RUGGED

150-Pound Brass Gate Valve with accurately guided wedge disc, non-rising stem. Recommended for service on steam, water, oil and gas lines where extra strength is required. Tight stem seal assured by high quality stuffing box packing and gland; can be repacked under pressure. Sizes ¼ to 3-inch. Also available with rising stem, screwed or flanged ends.

LOOK TO THE BROAD CRANE LINE FOR ALL YOUR PIPING EQUIPMENT NEEDS



DETREX Steam-heated Gyro Degreaser by Detrex Corporation, Detroit, Michigan.

The Complete Crane Line Meets All Your Valve Needs. That's Why—
More Crane Valves Are Used Than Any Other Make!

CRANE VALVES

CRANE CO., *General Offices:* 836 S. Michigan Ave., Chicago 5, Illinois
Branches and Wholesalers Serving All Industrial Areas

VALVES • FITTINGS • PIPE • PLUMBING • HEATING

Pump, Valve, And Assembly For Vacuum Pump

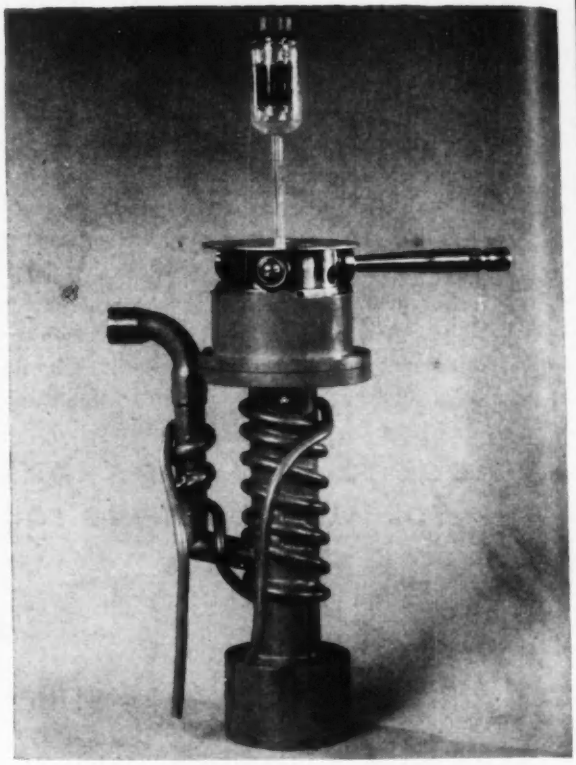
A compact new high-vacuum conversion pumping unit of large capacity for use with conventional rotary exhaust machines in the electronic tube manufacturing industry has been designed specially to evacuate standard electron tubes. However, it can also be used to pump other relatively small volume containers such as hermetically sealed relays, vials, instrument control elements, and vacuum condensers. For evacuating larger volume vessels or when back-filling operations are desired, a modification of the new unit will permit small solenoid valves to be used. This permits the inclusion of a "roughing" stage in the cycle, reducing pump oil deterioration and loss, and providing a simple means for introducing measured amounts of gases into the vessel.

Since the new MB-10 pump, valve and port assembly has a high forepressure tolerance of 400 microns, this eliminates the need for major conversion changes in installations of this new equipment. The pump will operate through most standard sweep and sliding valve combinations.

The pump operates at a pumping speed of 10 liters/sec. between 0.1 and 10.0 microns HG. It also offers ultimate vacuum of 5×10^{-5} mm HG which gives a wide performance range for overall flexibility of application.

The jet assembly on the pump is of such design that it may be easily disassembled for cleaning by turning one thumb nut, reducing cleaning problems to a minimum.

The need for air electrically operated valves to control the evacuation cycle through the "tube loading" and "pumping" stages is eliminated with this new equipment by positive action of the mechanically operated valve assembly which is specifically designed for small vessel application.



Distillation Products Ind., Rochester 3, New York

Adapters Speed Wiring and Equipment Change

A new line of adapters have been developed to permit convenient interchange of equipment between various wiring devices without the usual changing of plugs and jacks to meet different situations in various equipment.

No. 342 adapter with a dual-purpose binding post banana jack input has a standard phone plug output. The binding post also accommodates the standard banana plug; standard pin plugs can be inserted through the binding post.

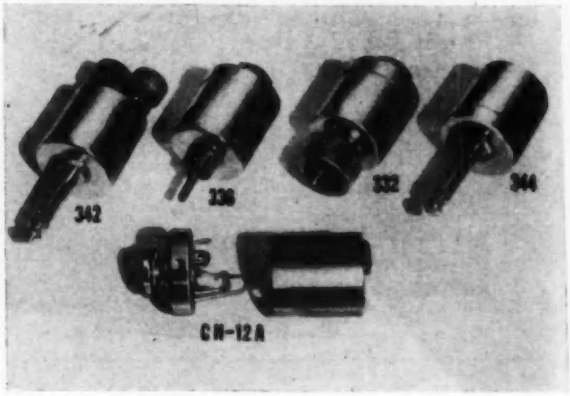
No. 346 adapter accommodates standard pin plugs (only) to the conventional phone plug.

No. 332 adapter has a standard phone jack input with a female microphone connector output. No. 334 is similar to No. 332 but has the phono connector input.

No. 336 adapter with a phone jack input and a phono connector plug, output makes it convenient to connect a microphone with a phone plug into an amplifier with a phono connector input. No. 338 is similar except for the microphone connector input to the adapter.

No. 334 plug adapter permits the connecting of connector plug into a conventional phone jack.

The new shielded jax CN-12A is the standard littel-jax made by this company, with a shield, assembled and made a part of the jack. After the leads have been soldered to the jack terminals, the cover snaps into the mating housing.

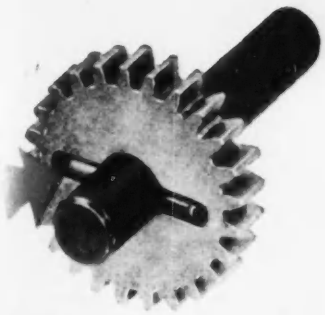


This component may be used where it is necessary to use a phone jack in a high impedance circuit.

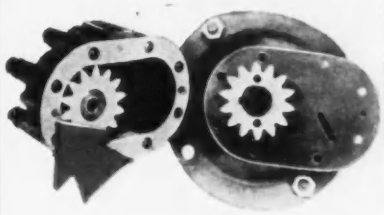
The finished housing of the shielded jax is 1 in. dia x $1\frac{1}{8}$ in. deep. The overall lengths of the adapters vary depending on the input and output connectors attached to ends of the basic housing.

Switchcraft, Inc., 1328 N. Halsted St., Chicago 22, Ill.

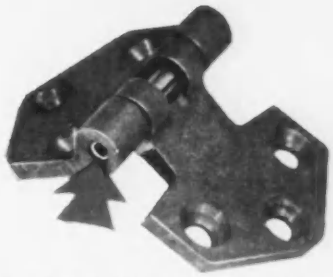
CONTINUED ON PAGE 230



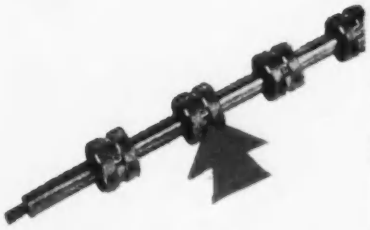
REPLACING A HUB ON A GEAR . . . Rollpin, self-retained in shaft, is simply snapped into molded slot to position sintered gear. This application, by Ditto Inc., effects major savings in assembly. Rollpin's high shear strength is particularly valuable here.



REPLACING A MACHINED PIN . . . In the lubrication pump assembly of the Cummins HR-400 diesel engine, two Rollpins are used as positioning dowels. Rollpins are self-retaining in production-drilled holes . . . quick to assemble and easy to remove.

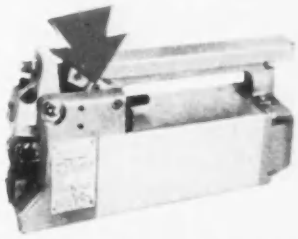


REPLACING A HEADED PIN . . . In this hinge pin application, Rollpin is simply and inexpensively driven in place, greatly reducing assembly costs. Constant spring tension holds Rollpin firmly in place . . . eliminates loosening of hinge due to wear.



REPLACING A SET SCREW . . . Paper feed rollers are quickly, economically pinned to shaft by Rollpins in this office machine made by Ditto Inc. Flush fit affords neat appearance . . . spring tension assures positive, permanent positioning of rollers.

REPLACING A RIVET . . . Rollpin serves as guide shaft for spring-loaded electrical interlock contacts. The Square D Company reports that rivet failure previously occurred at the clinched end under normal operating impact and vibration.



REPLACING A BOLT AND NUT . . . Rollpins act as fasteners and pivots for the linkages in this Miller Electric Welder. Rollpins may be used with a free fit in outer or inside members depending upon product design requirements.

6 more examples of assembly-time saving with ROLLPIN

TRADE MARK

Rollpins are slotted, tubular steel, pressed-fit pins with chamfered ends. They drive easily into holes drilled to normal tolerances, compressing as driven. Reaming, tapering, extra assembly steps are eliminated. Rollpins are *locked* in place by the constant pressure they exert against hole walls. Inserted with an automatic press or by hand, Rollpins are readily removable with a drift or pin punch—and reusable again and again.

Elastic Stop Nuts with the famous red collar are another ESNA® product

ESNA

FOR DESIGN INFORMATION—fill out and mail our coupon. If your plans include applications similar to those on this page—or clevis pins, keys, taper pins or stop pins—you can't afford to be without details on how much faster and cheaper Rollpin can do the job.

Dept. R6-112, Elastic Stop Nut Corporation of America
2330 Vauxhall Road, Union, New Jersey

Please send me the following free information on ESNA self-locking fasteners:

☐ Rollpin bulletin and sample Rollpins ☐ AN-ESNA conversion chart
☐ Elastic Stop Nut Bulletin ☐ Here is a drawing of our product. What fastener do you recommend?

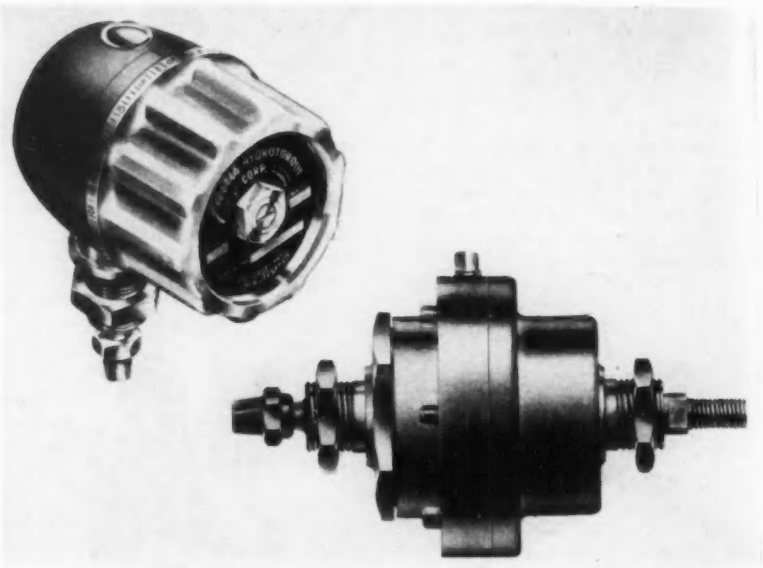
Name_____ Title_____

Firm_____

Street_____

City_____ Zone____ State_____

Remote Hydraulic Positioning Control



Hydrotorque, a hydraulic positioning control system designed for accuracy and power at remote distance, is used in the aircraft, marine, industrial, refinery, chemical and railroad industries, and will hydraulically position valves, throttles, engine speeds, winches and brakes, diesel engines, metering nozzles and a variety of other mechanical devices. The hydrotorque control system will indicate level, flow, static pressure, repeaters, rudder position or temperature.

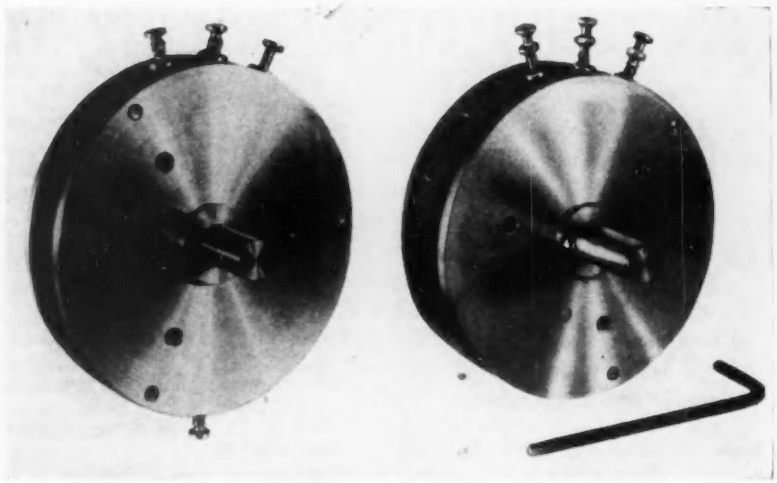
The device is a single tube system independent of outside energy, and features simplicity of principal and operation as well as economy in first cost and maintenance. Eliminating "sponginess", the hydrotorque control system gives the operator the "feel" of direct linkage, and permits positioning within a thousandth of an inch. In addition it is said that the hydrotorque system can be used in locations previously considered impracticable, including conditions of corrosion, high heat, and dusty locations.

The hydrotorque transmitters are flexible, and receivers can be supplied in a variety of combinations and in several variations of mounting methods. Calibration of dials can be made to read in inches of water, pounds of pressure, gallons per minute, up-down, or any given designation.

Hydrotorque remotely controlled valves for use in refinery, chemical and industrial services are also available to any requirements. In bronze, cast iron, cast steel, needle or 3 way, they can be used where remote operation is desired, and when complete freedom from fire hazard is required.

Farris Hydrotorque Corp., 705 *Commercial Ave., Palisades Park, N. J.*

Miniature Precision Potentiometers



A line of precision potentiometers of the miniaturized computing type is available as single units or ganged assemblies.

A cam-corrector which gives continuous adjustable advance of contact position with respect to shaft position is a feature of one series of these potentiometers.

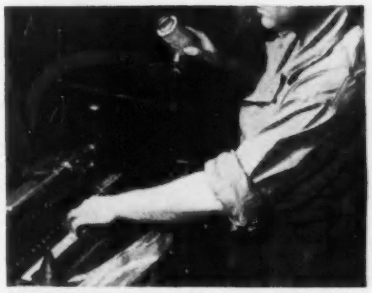
The series N potentiometers cover linear windings and those non-linear functions which can be fitted by tapping and shunting techniques. Series C incorporates a cam-corrector which makes possible accurate fitting of an additional class of more difficult functions. Both types may be ganged separately or intermixed.

Size of the potentiometers is $2\frac{5}{16}$ in. dia by 0.328 in. per stacked section for series N and $2\frac{5}{16}$ in. dia by 0.562 in per stacked section for series C. Shaft extensions and provisions for ganging and assembly with gear trains, synchros, and other components follow current engineering practice in precision analog computers.

Avion Instrument Corp., 299 State Highway 17, Paramus, N. J.

CONTINUED ON PAGE 232

It's a job for a SPECIALIST!



One of the many specialized steps in producing Sylphon and Bridgeport bellows assemblies. In the machine, a bellows tube is ready to be hydraulically formed. Operator holds a completely corrugated bellows in his right hand.

. . . and when it comes to producing bellows assemblies, that's a job for Fulton Sylphon or Bridgeport Thermostat. For we are specialists in this field, and have been for half-a-century.

That specialized experience can be a big help to you—and make savings for you, too. See how.

We will work with you to design and engineer bellows assemblies exactly suited to your needs. Then, we have the skilled personnel and facilities to take over the complete production job. You are relieved of all production problems and worries. You save time, trouble and money.

We produce bellows assemblies that are used throughout industry—as flexible connectors... for thermostatic devices . . . expansion joints . . . pressure controls . . . hydraulic mechanisms and for other uses. Whatever your requirements, find out how our specialists can help you get better results, at low cost. Write for helpful technical advice—ask for idea-packed Catalog VP.

FULTON SYLPHON
DIVISION
Knoxville 4, Tenn.

Robertshaw-Fulton
TEMPERATURE CONTROLS • BELLOWS ASSEMBLIES • BELLOWS DEVICES

BRIDGEPORT THERMOSTAT
DIVISION
Bridgeport 1, Conn.

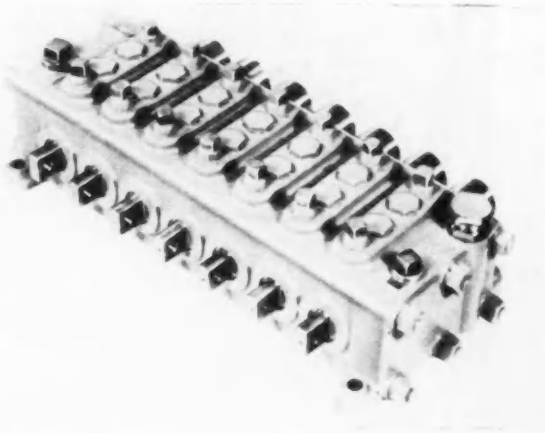
Larger Multiple Section Stack Valve

A new, larger ¾ in. multiple section stack valve, supplementing the ½ in. stack valve, is designed for series operation, permitting any number of devices to be actuated simultaneously under full or varying load, provided the total load does not exceed the relief valve setting. This makes it possible, for example, to lift simultaneously both ends of the blade on a grader, and also pefmit continuous rather than intermittent operation. The stack valve is used on other road machinery such as: ditching and dredging equipment, excavating machines, industrial tractors, and other types of mobile equipment.

Known as the S-25 valve, it incorporates pressure sealing by using O-ring seals between sections. This type of pressure sealing permits assembly and addition of sections in the field, if additional hydraulically operated attachments are used in the machine at a later date. An inlet section with an adjustable relief valve gives the overload protection, while check valves in each directional control section insures positive cylinder control under load.

As each section is an individual, standard, unit, a valve assembly or "stack" may be tailored to exact requirements with various inlet, four-way, three-way and outlet sections.

The S-25 series is rated for 25 gpm, and a maximum recommended operating pressure of 1500 psi. Any number of sections of 10 or less may be assembled.



Sundstrand Machine Tool Co., Rockford, Ill.

Rotary Accelerator for Testing Small Mechanisms

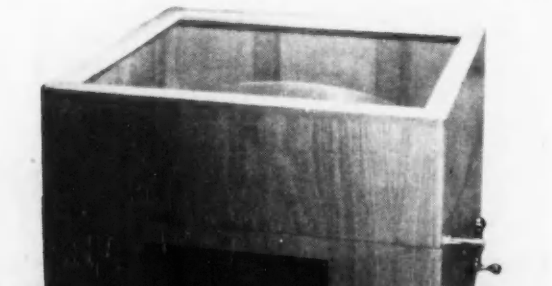
Having an acceleration range of from 0.1 g to 100 g, this new rotary accelerator gives a controlled variable centrifugal acceleration for calibrating or testing instruments, electronic sub-assemblies, small mechanisms, and other similar equipment.

The rotating table is a dural disk 16 in. in diameter on which a test object weighing up to 5 lb may be mounted. Means for locating a counterbalancing weight is provided. The table is driven by a ⅛ hp, 3,600 rpm electric motor through a variable speed transmission with a range of 0-1,000 rpm.

For testing electrical devices, six solid coin silver slip rings are used, each with two silver graphite brushes. Power and signals are transmitted with low noise levels at all rotational speeds. Two of the slip rings are rated at 115 v, 5 amp and the remaining four are rated at 115 v, 1 ampere.

The approximate speed of the rotating table is indicated by a graduated dial, calibrated in rpm, which is coupled to the hand-operated transmission control. For exact measurement, four stroboscopic disks are provided, each with two check points. The harmonics of the check points serve as intermediate check points.

The number of g units applied to the object under test is determined by multiplying the number below the stationary dot pattern on the stroboscopic disk by the radial distance of the object on the rotating table. The case of the accelerator is made of heavy plywood.



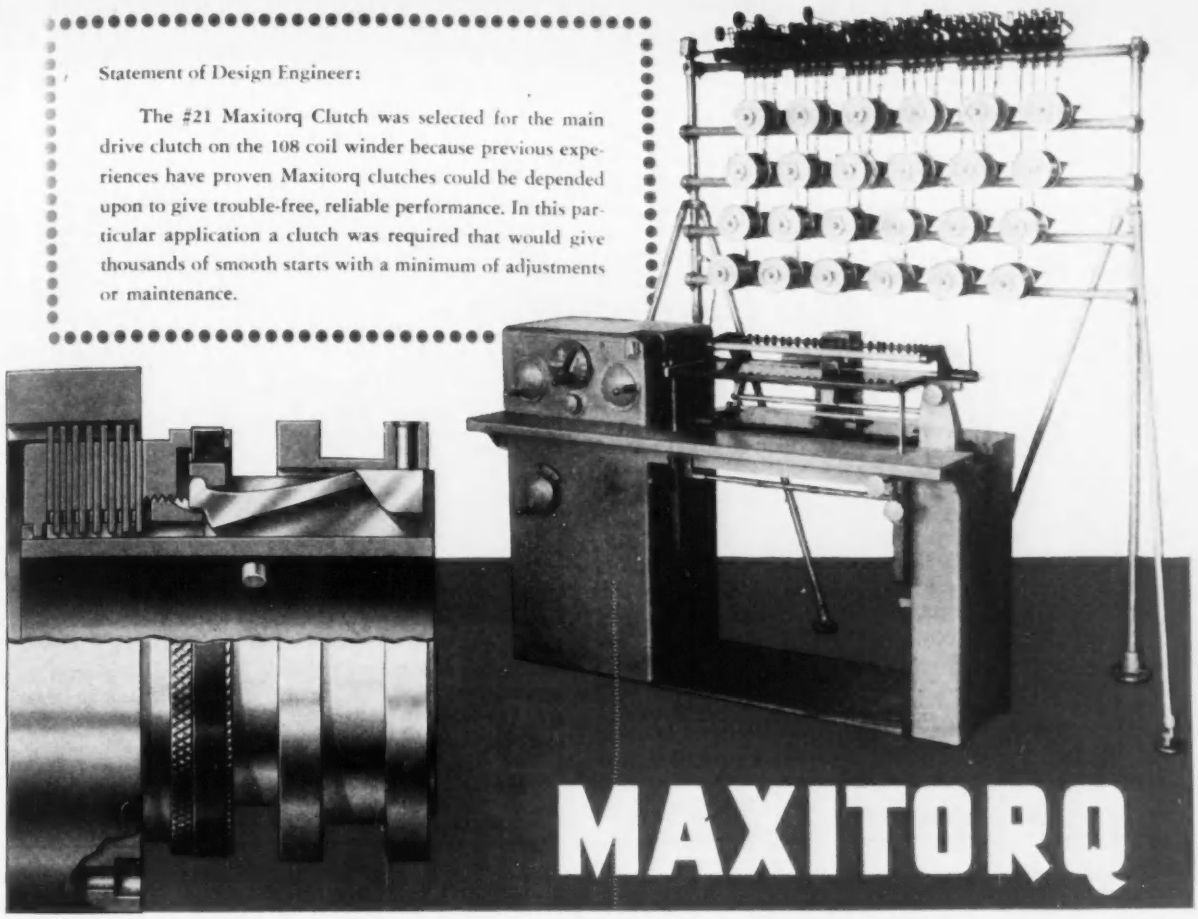
Stratham Development Corp.,
12411 *West Olympic Blvd., Los Angeles 64, Calif.*

THE OVERALL HEIGHT of a new miniature solenoid is 1⅜ inches. The device is a special side-mounted connector solenoid made for a single-point fueling system for commercial and military aircraft. This unit activates a slide valve mechanism in the fuel level control system in each tank, only possible by means of the right angle mounting of the electrical receptacle. The unit exerts a 2 lb pull at ⅛ in. stroke at 18 volts d-c, and may be used in ambient temperatures to 300 F. Weight: 0.29 lb. overall height, 1⅜ in. Designed to MIL 4040 specifications. Lafayette Engineering & Development Co., 9675 Santa Monica Blvd., Beverly Hills, Calif.

CONTINUED ON PAGE 234

Statement of Design Engineer:

The #21 Maxitorq Clutch was selected for the main drive clutch on the 108 coil winder because previous experiences have proven Maxitorq clutches could be depended upon to give trouble-free, reliable performance. In this particular application a clutch was required that would give thousands of smooth starts with a minimum of adjustments or maintenance.



MAXITORQ

KEEPS GOOD COMPANY

The Maxitorq floating disc clutch is making a lot of good friends these days . . . as evidenced by the statement above from Universal Winding Company, Providence, R. I.

Their No. 108 Electrical Coil Winding Machine, winner of an award from "Electrical Manufacturing" for product design, is equipped with a Maxitorq Clutch . . . one of many new Maxitorq installations in textile machinery.

If you are a product or machine designer you will discover in Maxitorq the solution to many problems in power transmission. Maxitorq gives you 8 sizes from ¼ to 15 H.P. in standard sizes . . . 6 sizes in the Automatic Overload Release type. Compact streamlined design, precision machining and a variety of rearrangements in installation and driving hookups make Maxitorq a versatile control for Machine Tools, Power Trucks, Textile and Printing Machinery, Packaging and Labeling equipment, Mining, Laboratory, Ordnance . . . and for many other types of industrial power operated machinery.

A high type of engineering service is available on request. Write us for details.

SEND FOR CATALOG
No. PE11

THE CARLYLE JOHNSON MACHINE COMPANY
MANCHESTER • CONNECTICUT

AC/BE

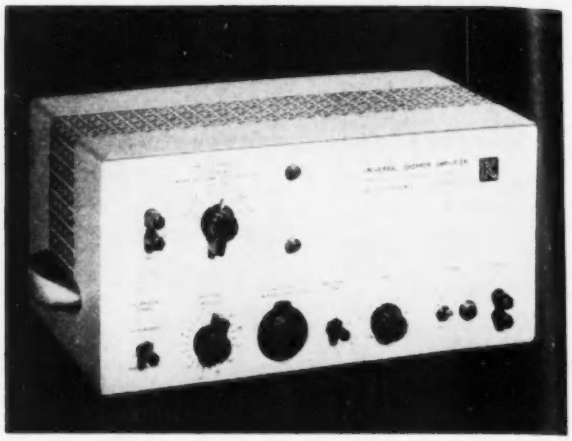
New High Gain Chopper Amplifier

Designated the model 300 universal chopper amplifier, this new instrument has a maximum gain of 800,000, frequency response of 0-500 cps, input impedance of 1 megohm, noise and drift within 25 microvolts, or 2 percent of full-scale output. By connecting the proper capacitance across the equalizer terminals at the rear of the chassis, the high-frequency response can be increased to about twice the low-frequency gain, compensating for the falling off of a recorder.

Other features of the amplifier include stabilized gain and a new mechanical chopper with a rate of 5,000 contacts per second. The input bucking potential includes both step and continuous controls, and allows the zero to be offset 150 times full scale. The controls are calibrated within about 10 percent of the actual bias supplied. A calibrator key gives d-c step functions of either 100 or 500 microvolts, following the input attennuator. Accuracy is within approximately 3 percent.

Any pen recorder can be used with the instrument to indicate the small potentials developed by thermocouples, strain gages, and other sources in which the d-c and a-c components are of interest. Output of the amplifier will deliver up to 25 milliamperes, and can develop ±80 volts.

The new amplifier drives practically all recording galvanometers. Series and damping resistor terminals permit attenuating the output to work with sensitive mirror galvanometers. Terminals are also used for equalizing recorders. The high level d-c output also works with pen recorders, recording galvanometers, and cathode ray oscilloscopes.



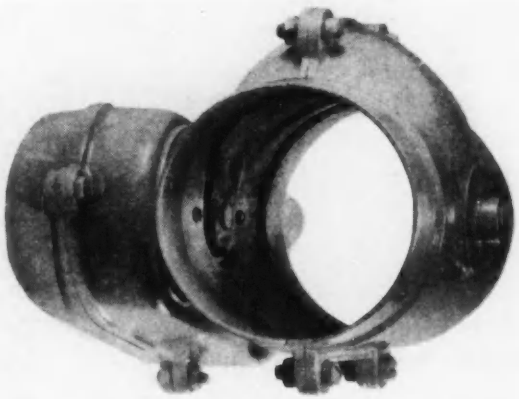
Keithley Instruments, 3868 *Carnegie Ave., Cleveland* 15, *Ohio*

Air Control Valve Operates Automatically

A new automatic air-control valve, for use with air suction systems and dust collectors on units such as metal grinding and polishing machines, wood jointers, planers, sanders, table saws, and other similar equipment, is simple in design, and can be fitted to any machine, pipe or installation within its scope.

Known as the ventomatic air control valve, it opens and closes automatically as the machine switch is turned on and off, preventing the continual exhausting of warm air from the room when the machine is not operating.

Improvement of efficiency in the entire suction system results from concentrating suction only on those machines that are actually operating. When the ventomatic valve is open there is no obstruction in the air passage, eliminating the possibility of catching chips, dust, lint or shaving threads. The operation of the valve is mechanically controlled by a solenoid, and is no way affected by the air stream. The new ventomatic air control valve is available in sizes to fit 3, 4, 5, 6, 7 and 8 inch air ducts.



Kindt-Collins Co., 12653 *Elmwood Ave., Cleveland* 11, *Ohio*

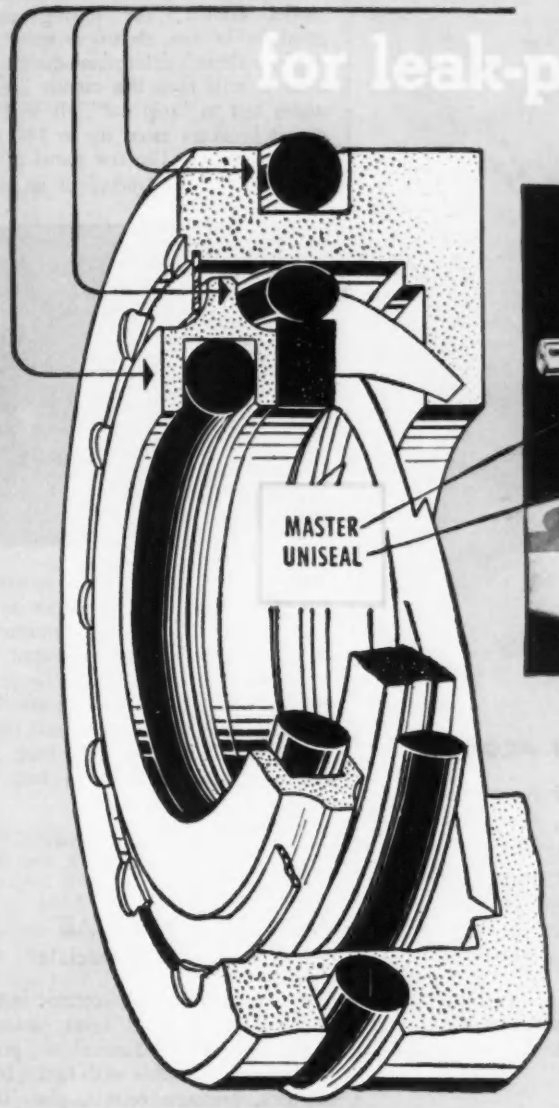
A SPECIAL DRAWING GRADE OF NYLON STRIP is being used to draw and form insulating shells for small type servomotors. The specific material used is standard FM10001 nylon strip, 0.015 in. thick by 2 in. wide. The material's toughness permits forming without fracturing. It will not support fungus growth and meets the specifications for operation at 105 C, required of class A insulation. It will remain form stable for higher intermittent temperatures. Atco Electronics Corp., 258 Wyth Ave., Brooklyn, N. Y.

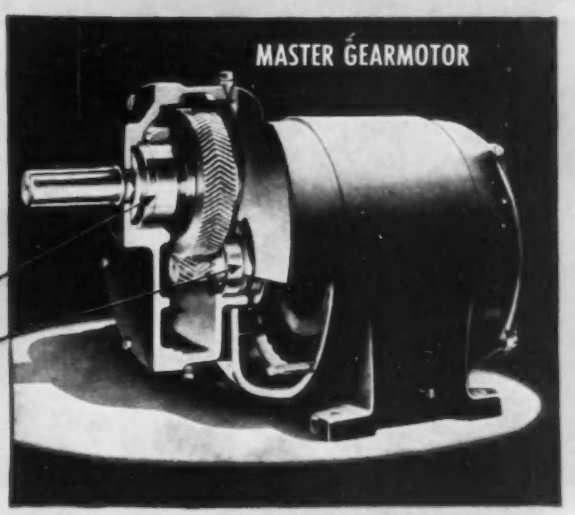
CYLINDERS OF VARIOUS SIZES containing heating elements are made with varying surface watt density, manually and automatically controlled in the cylinders for any preset temperature from 100 to 700 F or more. They can be made for single, two or three phase in various voltages. Cartridges are being furnished in sizes of $7\frac{3}{8}$ in. dia x 11 in. long, and $14\frac{1}{2}$ in. dia. x 11 in. long. Furtex, Inc., 258 E. Third St., Mt. Vernon, N. Y.

CONTINUED ON PAGE 236

3 PRP "O" RINGS seal the UNISEAL

for leak-proof service!





The Master Electric Company's Uniseal—result of 25 years development—employs 3 PRP "O" Rings for simple design and leak-proof, long life performance. Ingenuous use of PRP "O" Rings in this modern design produces a free-running, unstrained rotating shaft for Master Gearmotors, where oil leakage must be prevented.

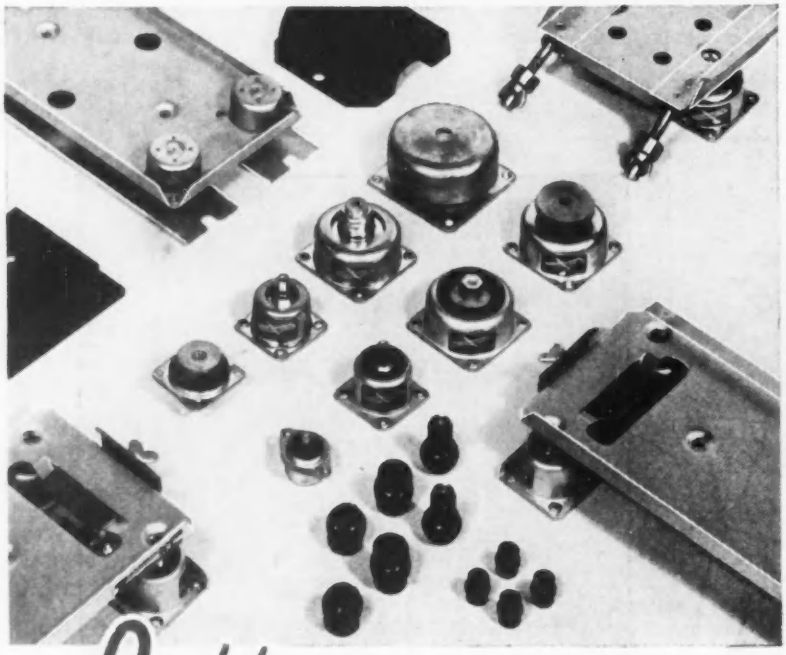
Everyone's finding it's PRP "O" Rings for top quality, long life and economy. Write or phone for your free copy of our Handbook of "O" Ring design information.

The name "*Precision*" on "O" Rings is like "*Sterling*" on silver.

Precision Rubber Products
CORPORATION
The "O" Ring Specialists
Dept. 3, Oakridge Drive, Dayton 7, Ohio

SHOCK and VIBRATION NEWS

BARRYMOUNTS FOR ASSURED CONTROL OF SHOCK AND VIBRATION



the ***Right*** *answer*

TO YOUR SHOCK AND VIBRATION PROBLEMS

will be found in this complete family of Barrymounts. From tiny, ounce-rated unit mounts . . . through ruggedized bases . . . to heavy-duty isolators for industrial machinery . . . Barrymounts meet all your needs. FREE CATALOGS give you details of dimensions, load ratings, and military specifications met by these effective vibration and shock isolators.

FOR AIRCRAFT SERVICE

Catalog 509 describes ALL-METL Barrymounts for use at extreme temperatures. Catalog 502-A covers Air-damped unit mounts and bases.

FOR INDUSTRIAL USES

Catalog 504-B describes the general line of Barrymounts rated from 1/8 ounce to 3300 pounds. Catalog 607 covers the use of Barrymounts with heavy industrial machinery.

And for SPECIAL PROBLEMS

ask the advice of our Field Engineering department, organized to apply our wide experience to your particular needs.

Address all inquiries to:

THE **BARRY** CORP.

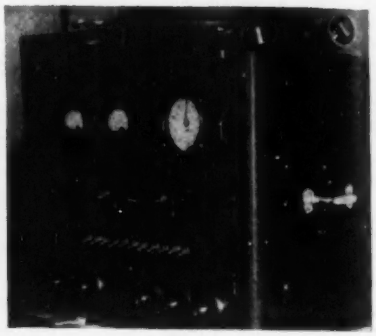
730 PLEASANT ST., WATERTOWN 72, MASSACHUSETTS

SALES REPRESENTATIVES IN

Atlanta Chicago Cleveland Dallas Dayton Detroit Los Angeles
Minneapolis New York Philadelphia Phoenix Rochester St. Louis
San Francisco Seattle Toronto Washington

Portable Circuit Breaker For Field Testing

A portable circuit breaker tester, model CBT-1, for testing circuit breakers in the electrical system of modern aircraft determines the elapsed time it will take the circuit breaker under test to "trip out". It will test circuit breakers rated up to 150 amp on a 28 v d-c. The test panel of this new tester is constructed of an insulating material and provides mounting for a d-c voltmeter, a dual scale 0—30 amp and 0—150 amp d-c ammeter, a 30 and 150 amp negative input terminal ports, a d-c ammeter range selector switch, eleven loading switches, and a 1000 second manual reset timer. Ten feet of stranded two wire #4 rubber covered cable with two test clips, are included.



Greer Hydraulic Inc.,
454 18th St., Brooklyn 15, New York

Level Indicator for All Containers and Materials

The telstor, a new electronic instrument for continuous level measurement, without mechanical or pneumatic means is usable with tanks, bins, hoppers, pressure vessels, glass-lined vessels, fuel tanks, water reservoirs or practically any type container. Materials that may be measured include almost any type of liquid, viscous fluid or granular solids.

The device consists of an electronic unit, an insulated electrode and an indicator unit. The electronic unit is mounted adjacent to the tank, bin or grain elevator. The electrode is mounted from top to bottom in the tank or bin, and connected by coaxial cable to the electronic unit. The indicator unit may be mounted at a central or remote location, up to one mile from the bin, or tank.

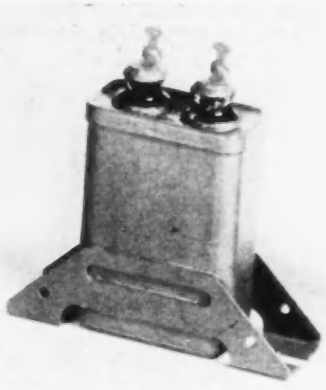
The electrode in the container becomes one side of a radio frequency capacitor, and the walls of the bin or tank the other side. The material

stored in the tank or bin increases the capacity between the electrode rod and the container walls, in proportion to the depth to which the electrode is immersed. The level of the stored material is then shown on the indicator unit scale meter.

Fielden Instrument Corp., 2920 N 4th St., *Philadelphia* 33, *Pa.*

Capacitor Holds Charge 200 Days

Feature of a new line of capacitors is its ability to hold its charge for as much as 200 days or longer, making possible computing devices in which it would be necessary to store



information for an extended period of time.

Shown above is the type D of this series which is hermetically sealed. The case material is lead coated steel. The terminals are of treated glass of the stand-off type. Winding is non-inductive. The operating temperature range is —80 C to + 75 C. Capacity tolerance is ±10 percent, but units are available in ±5, 3, 2, and one percent.

Height of the largest model, the 6DY10 with a capacity of 0.1 mfd, is $1\frac{5}{16}$ in., width is $1\frac{5}{16}$ inches.

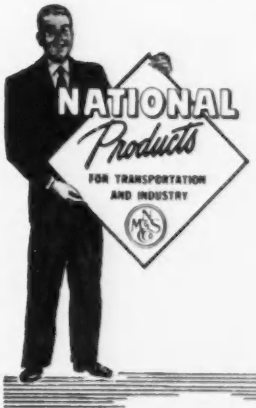
Industrial Condenser Corp., 3243 N. *California Ave.*, *Chicago* 18, *Ill.*

Electric Ring Heaters

These heaters can be used for both space and contact units for assembly into hot plates, pots, defrosters, vulcanizers, moulds, dies, water heaters for distillation equipment, on airplanes, and for correct operational temperature control on gyros in gun sights. Special advantages are concentrated heat and ease of installation.

The six sizes run from 2 in. OD, $\frac{1}{4}$ in. thick, to 6 in. dia. $\frac{5}{16}$ in. thick. There are two standard types. One,

Castings by National
selected for Quality and Dependability



Products bearing these familiar trademarks have all established enviable reputations for quality and dependability. And to guard product reputations, these manufacturers *continue* to specify castings by National —one of the Nation's largest founders.

DETROIT QUALITY GEARS · Nash · STUDEBAKER · HYDRAPOWER Gear Pumps · FRUEHAUF TRAILERS · HUDSON · Ford · GEMMER MANUFACTURING CO. · HYDRAGUIDE

National's unparalleled experience in producing malleable, heat-treated malleable, and steel castings is at your disposal. Sales offices and engineering facilities are located at all five strategically located plants.

A-5605

PLANTS LOCATED IN Sharon, Pa., Cleveland 6, Ohio, Indianapolis 6, Ind., Melrose Park, Ill., and Chicago 50, Ill.

SEE "This Moving World"

A 16mm technicolor film. Narrated by Edwin C. Hill, this 27-minute film tells how malleable iron is made . . . tested . . . used . . . how its production economy, ductility, machinability, toughness will give you a better finished product. Available for group showings.

NATIONAL Products FOR TRANSPORTATION AND INDUSTRY

NATIONAL MALLEABLE and STEEL CASTINGS COMPANY
CLEVELAND 6, OHIO Est. 1868

Secure LOOSE PARTS with Bead Chain

A MUST for Military Products

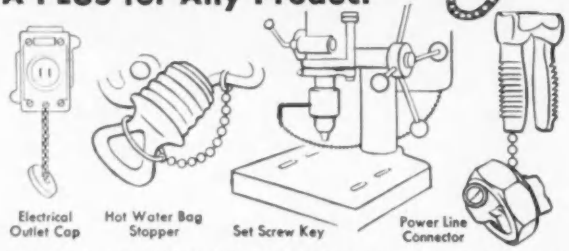
Canteen Cap Courtesy Wyandotte Chem. Co.

Sterilizer Lamp Cap

Aircraft Access Plate

Ship Alarm Hammer

A PLUS for Any Product



Electrical Outlet Cap · Hot Water Bag Stopper · Set Screw Key · Power Line Connector

When a householder or industrial worker mislays an essential part of your product, he may suffer inconvenience or minor hardship. But, loss of some important small part of military equipment may mean that men are lost, too.

As a positive leash for straying parts, nothing can equal Bead Chain! Non-kinking, free-swiveling action assures full freedom in using the part or tool secured. It is small, light, attractive . . . yet strong enough to hold under abusive strains.

Check your product now! Leash any part that may stray. It costs only a penny or two, as a rule, to add a Bead Chain retainer that's worth dollars as a trouble-saver for your customers.

Kinkless Chain of a Thousand Uses

Design ingenuity can employ Bead Chain in many unique ways to gain new product appeals, please buyers, cut costs. For example: A low-cost non-slip chain drive for business machines, TV tuners, venetian blinds etc. Pulls for electric lights, fans, registers, zippers. Trimming for leather goods, wearing apparel, etc. Suspensions for light bowls and signs . . . and in countless other ways.

Get "Bead Chain" . . . Get 4 Plus Values

As the world's largest producer of Bead Chain, the Bead Chain Company offers you: (1) Dependable quality and delivery. (2) Unmatched application help based on experience with thousands of users. (3) Widest selection of chain sizes, styles, metals, finishes—and attachments to fit every need. (4) Money-saving assembly service which provides made-to-your-order assemblies.

NEW! Bead Chain Catalog-Data Folder. Write today!

BEAD CHAIN®

The Bead Chain Mfg. Co., 92 Mt. Grove St., Bridgeport, Conn.

in rust-resisting steel sheath, for temperatures up to 750 F: the other, in stainless steel sheath, for temperature up to 1200 F. Steel sheath wattage runs from 75 to 800. Stainless steel, from 100 to 1000.

Both are supplied in either 115 or 230 v, or in special voltage, if required.

Except for the smallest size, the units can be had in three-heat construction. Flexible lead wires can replace the standard threaded stud terminal construction.

Vulcan Electric Co., Danvers, Mass.

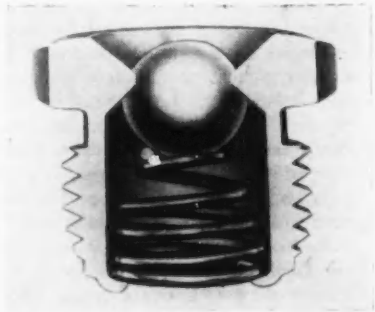
Grease Fitting Has Advantage of Flush Mounting

The problem of protruding heads of ordinary grease fittings being knocked off by a heavy blow or collision is remedied by a new line of flush-type grease fittings just introduced.

The fittings are made with a ball check. Supported by a spring, the ball prevents oil or grease leakage caused by a back pressure. The ball, which holds the opening normally closed and cannot be unseated, is depressed for oiling or greasing.

The back-up spring is designed so passage through it at the point of fullest depression is greater than the opening at the top of the fitting. This provides free flow of lubricant.

Other products made by the manufacturer include: drain plugs, hydraulic couplers, adapters, easy-out

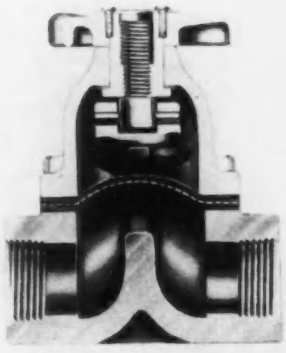


tools, grease hose, fitting tools, pressure guns, swivels, spring lubricators, control valves, top oilers, as well as other types of grease fittings—including the new giant buttonhead one-piece construction fitting.

Universal Lubricating Systems Inc., Oakmont, Pa.

Plastic General-Purpose Diaphragm Valves

Tough, odorless, and non-toxic, a new general purpose diaphragm valve is molded of a polyethylene plastic compound, and has wide use for handling corrosive chemicals. Metal never comes in contact with the liquids handled, and the diaphragm may be of rubber, neoprene, or polyethylene. The bonnet assembly is sealed off from



the solution, and the valve has no stuffing box to leak. It can be serviced without removing from the line, and all parts are interchangeable.

The new valves are available in all standard sizes from ½ to 2 in., and threaded for standard pipe threads. Its working pressure is 50 psi at 77 F.

American Hard Rubber Co., 93 Worth St., New York 13, N. Y.

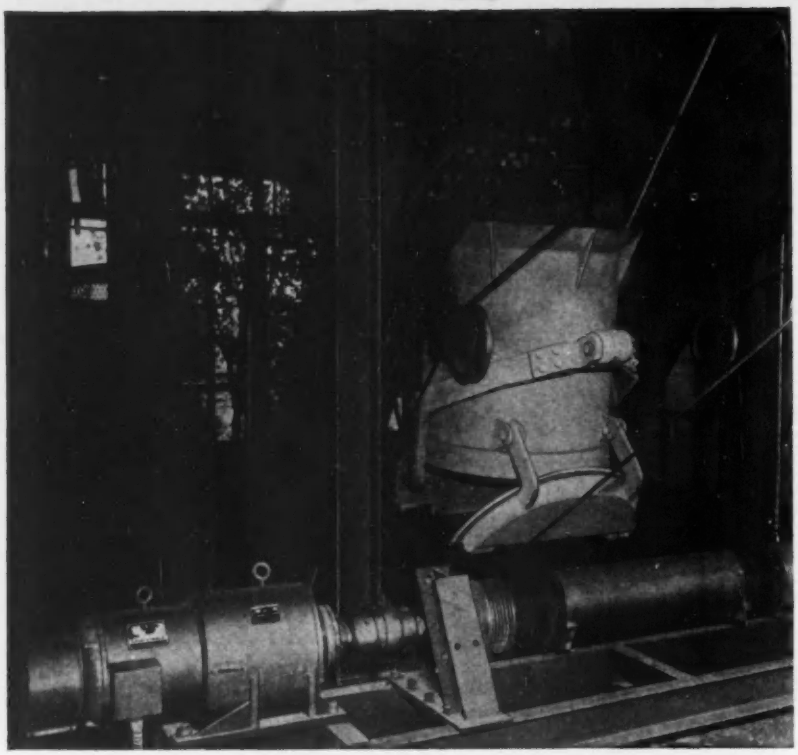
High Reverse Voltage Rectifier

A new selenium rectifier cell rated 36 v (RMS), designed especially for application where size and weight are primary considerations, has been developed.

Because the individual cells are rated at 36 volts RMS, a rectifier stack made up of these cells will not only withstand a higher reverse voltage, but will require fewer cells for the same voltage output. As a result, losses are proportionately less, and the efficiency of the stack is increased.

The new rectifier unit is said to be well adapted for use in aircraft and in many types of military equipment. Its compactness and lighter weight

dependable timing
INTERVAL TIMERS
TIME DELAY RELAYS
to product performanc
PERCENTAGE TIMERS
RUNNING TIME METERS
Cramer
As specialists in TIME as a factor of CONTROL, we have developed a wide range of timing devices, extensively used on electrically-operated commercial and industrial equipment where accurate, dependable timing is essential to insure efficient produc performance . . . to add convenience of operation . . . to prevent work spoilage and protect equipment itself.
Although the majority of timing-problems can be effectively solved by devices considered "standard" in our line, we have had a great deal of experience in the design of special devices to meet specific requirements . . . and will welcome the opportunity to help solve your timing problem. Write us for complete information.
PULSE TIMERS
SYNCHRONOUS MOTORS ALSO CLUTCH REVERSIBLE AND CHART DRIVE TYPES)
THE R. W. CRAMER CO., INC.
BOX 7, CENTERBROOK, CONN.



"YEARS OF LIFE IN TOUGHEST FOUNDRY SERVICE"

. . . say Whiting Engineers of Star-Kimble Gear-Brakemotors

The Whiting Skip Charger shown in the photo works two shifts a day, handling heavy charges of metal, coke and stone for the cupola. The Skip Charger must stop the load *accurately* and hold it *positively*. Equipment is subjected to intense heat and heavy concentrations of dirt in the air.

For tough service like that, Whiting powers its equipment with Star-Kimble Gear-Brakemotors, which have *proved* their ability to give years of service with little need for maintenance attention. The quick-acting, positive brake requires little or no adjustment; the motor and speed reducer provide a high factor of safety for heavy overloads. AND . . . motor, brake and speed reducer are a *single*, compact, well-protected unit.

For information on Star-Kimble Brakemotors, with or without the speed-reducing feature, write for Bulletin B-501-A.

STAR-KIMBLE

MOTOR DIVISION

MIEHLE PRINTING PRESS AND MFG. CO.

211 Bloomfield Avenue Bloomfield, New Jersey

also permit its use in battery charges and power supplies. Other features include rugged construction, long life, and a high operating temperature which results in less derating. The unit is available in a wide variety of sizes.

Federal Telephone and Radio Corp., Clifton, N. J.

Angle Type Toggle Valve

Angle type toggle valves for use in controlling high vacuum systems or pressures up to 500 psi under certain conditions have been designed for use in installations where the angle type is more adaptable than straight pattern valves. The quick acting angle type toggle valves of the lever type can be used in any application requiring a quick opening valve having no

leakage through stem or seat, and will not leak under pressure.

The internal materials of construction are brass and synthetic rubber. Seat material is normally synthetic rubber, but can be altered to meet specific conditions of operation.

Hoke, Inc., 197 S. Dean St., Englewood, N. J.

Molded Nylon Cable Hangers

A complete line of pre-formed, molded nylon cable hangers, called Nyloclips, are lightweight, flexible, have a high tensile strength, and are unaffected by oils, gasoline, alcohol, or hydraulic fluids, including non-inflammable types. Resistant to sustained temperatures from —60 F to 250 F, the hangers retain their original shape, and require no shaping or forming on the job. Eleven standard diameter size hangers, can accommodate single cables or groups of cables from $\frac{3}{16}$ to 2 inches. Several sizes permit diameter adjustment in installation.

Burndy Engineering Co., Norwalk, Conn.

MEETINGS

November 17-18

OPERATIONS RESEARCH SOCIETY—First Regular Meeting, National Bureau of Standards, Washington, D. C.

November 17-19

NATIONAL, PAINT, VARNISH AND LACQUER ASSOCIATION—64th Annual Convention, Palmer House, Chicago.

November 19

AMERICAN STANDARDS ASSOCIATION—34th Annual Meeting, The Waldorf-Astoria, New York City.

November 20-22

AMERICAN ZINC INSTITUTE—Fall Meeting of the Galvanizer Committee, Bismarck Hotel, Chicago, Ill.

November 30-December 5

AMERICAN SOCIETY OF MECHANICAL ENGINEERS—Annual Meeting, Statler Hotel, New York City.

December 1-6

NATIONAL EXPOSITION OF POWER AND MECHANICAL ENGINEERING—Grand Central Palace, New York City.

December 3-5

SOCIETY FOR EXPERIMENTAL STRESS ANALYSIS—Annual Meeting, Hotel McAlpin, New York City.

January 12-16

SOCIETY OF AUTOMOTIVE ENGINEERS—Annual Meeting and Engineering Display, Sheraton-Cadillac Hotel, Detroit, Mich.

January 19-22

PLANT MAINTENANCE CONFERENCE AND SHOW—Public Auditorium, Cleveland, Ohio.

January 23

MALLEABLE FOUNDERS' SOCIETY—General Meeting, Hotel Cleveland, Cleveland, Ohio.

January 26-29

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS—Annual Meeting, Conrad Hilton Hotel, Chicago, Ill.

January 26-30

INTERNATIONAL HEATING AND VENTILATING EXPOSITION—International Amphitheatre, Chicago, Ill.

February 4-6

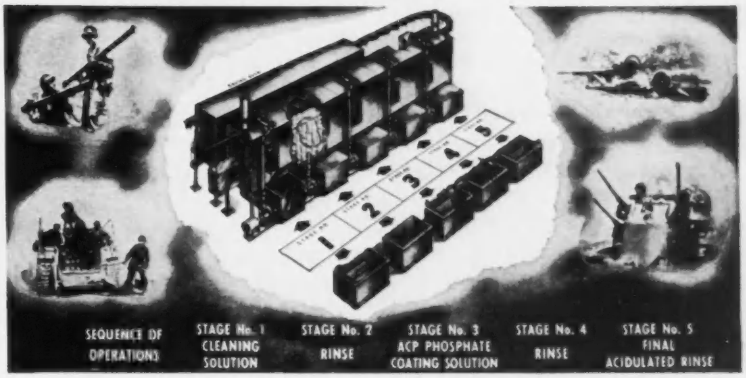
WESTERN COMPUTER CONFERENCE—First Meeting, Hotel Statler, Los Angeles, Calif.

AMERICAN CHEMICAL PAINT COMPANY

AMBLER CHEMICALS ACP PROCESSES PENNA.

Technical Service Data Sheet

Subject: METAL PRESERVATION AND PAINT PROTECTION WITH ACP PHOSPHATE COATING CHEMICALS


SEQUENCE OF OPERATIONS
STAGE No. 1 CLEANING SOLUTION
STAGE No. 2 RINSE
STAGE No. 3 ACP PHOSPHATE COATING SOLUTION
STAGE No. 4 RINSE
STAGE No. 5 FINAL ACIDULATED RINSE

U.S. ARMY PHOTOGRAPHS COURTESY OF "ORDNANCE MAGAZINE"

Typical spray and dip phosphating equipment and some ordnance products that are now given a protective phosphate coating for extra durability under all kinds of severe exposure conditions. Both military and civilian applications of ACP phosphate coating chemicals are shown in the chart below.

SELECTION CHART OF ACP PROTECTIVE COATING CHEMICALS FOR STEEL, ZINC, AND ALUMINUM

METAL	ACP CHEMICAL	OBJECT OF COATING	TYPICAL METAL PRODUCTS TREATED	GOVERNMENT SPECIFICATIONS
STEEL	"GRANODINE" Zinc Phosphate Coating Chemical	Improved paint adhesion	Steel, iron, or zinc fabricated units or components, automobile bodies, refrigerators, washing machines, cabinets, etc.; projectiles, rockets, bombs, rifles, small arms, belt links, cartridge tanks, vehicular sheet metal, tank bolts and links, recoilless guns, etc.	MIL-S-5002 JAN-C-490, Grade 1 JAN-F-495 U.S.A. 57-0-2, Type II, Class C U.S.A. 51-70-1, Finish 22.02, Class C U.S.A. 50-60-1 16 E4 (Ships)
STEEL	"PERMADINE" Zinc Phosphate Coating Chemical	Rust and corrosion prevention	Nuts, bolts, screws, hardware items, tools, guns, cartridge clips, fire control instruments, metallic belt links, steel aircraft parts, certain steel projectiles and many other components.	MIL-C-16232 U.S.A. 57-0-2, Type II, Class B U.S.A. 51-70-1, Finish 22.02, Class B Navy Aeronautical M-364 U.S.A. 72-53 (See AN-F-20)
STEEL	"THERMOIL-GRANODINE" Manganese-iron Phosphate Coating	Wear-resistance anti-galling, safe break-in of friction or rubbing parts. Rust proofing.	Friction surfaces such as pistons, piston rings, gears, cylinder liners, camshafts, tappets, crankshafts, rocker arms, etc. Small arms, weapon components. Hardware items, etc.	MIL-C-16232 U.S.A. 57-0-2, Type II, Class A U.S.A. 51-70-1, Finish 22.02 Class A Navy Aeronautical M-364 U.S.A. 72-53 (See AN-F-20)
STEEL	"GRANODRAW" Zinc-iron Phosphate Coating	Improved drawing, extrusion, and cold forming	Blanks and shells for cold forming, heavy stampings; tube; tubing for forming or drawing; wire; rod; etc.	———
ALUMINUM	"ALODINE" Protective Coating	Improved paint adhesion and corrosion resistance	Aluminum products of similar design such as refrigerator parts, wall tile, signs, washing machine tubs, etc; aircraft and aircraft parts; bazookas (rocket launchers), helmets, belt buckles, clothes dryers, clothesline, rocket motors, etc., aluminum strip or sheet stock.	MIL-C-5541 (See also QPL-5541-1) MIL-S-5002 AN-F-20 U.S. Navord O.S. 675 16 E4 (Ships) AN-C-170 (See MIL-C-5541) U.S.A. 72-53 (See AN-F-20)
ZINC	"LITHOFORM" Zinc Phosphate Coating Chemical	Improved paint adhesion	Zinc alloy die castings; zinc or cadmium plated sheet or components; hot dip galvanized stock; galvanneal; signs; siding; roofing; galvanized truck bodies; etc.	QQ-P-416 RR-C-82 JAN-F-495 AN-F-20 U.S.N. Appendix 6 U.S.A. 72-53 (See AN-F-20)

CHEMICALS ACP PROCESSES

WRITE FOR DESCRIPTIVE FOLDERS ON THE ABOVE CHEMICALS AND FOR INFORMATION ON YOUR OWN METAL PROTECTION PROBLEMS

CHEMICALS ACP PROCESSES

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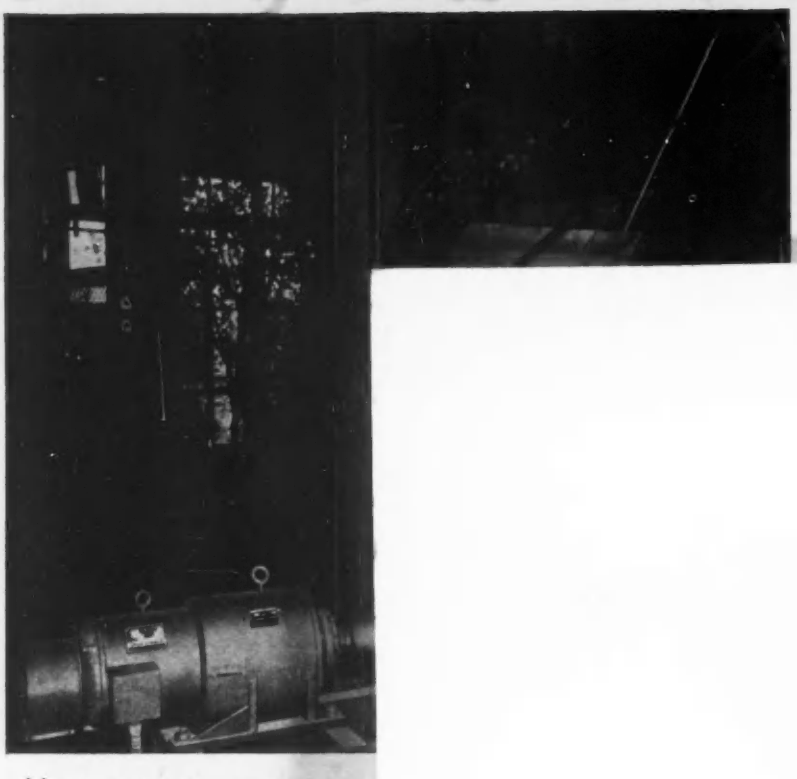

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For tough service like that, V
Star-Kimble Gear-Brakemotors,
give years of service with little m
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motor and speed reducer provid
overloads. AND . . . motor, br
compact, well-protected unit.

For information
out the speed-r

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211 Bloomfield Avenue Bloomfield, New Jersey

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AMERICAN CHEMICAL PAINT COMPANY

AMBLER CHEMICALS ACP PROCESSES PENNA.

Technical Service Data Sheet

...ON AND PAINT PROTECTION

...ATE COATING CHEMICALS

...OTOGRAPHS COURTESY OF "ORDNANCE MAGAZINE"

...ing equipment and some ord- ...given a protective phosphate ...er all kinds of severe exposure ... civilian applications of ACP ...re shown in the chart below.

...NG CHEMICALS FOR STEEL, ZINC, AND ALUMINUM

...PICAL METAL ...UCTS TREATED	GOVERNMENT SPECIFICATIONS
...inc fabricated units or com- ...bile bodies, refrigerators, ...es, cabinets, etc.; projec- ...mbs, rifles, small arms, ...idge tanks, vehicular sheet ...s and links, recoilless	MIL-S-5002 JAN-C-490, Grade 1 JAN-F-495 U.S.A. 52-0-2, Type II, Class C U.S.A. 51-70-1, Finish 22.02, Class C U.S.A. 50-60-1 16 E4 (Ships)
...ws, hardware items, tools, ...clips, fine control instru- ...belt links, steel aircraft ...steel projectiles and many ...ts.	MIL-C-16232 U.S.A. 52-0-2, Type II, Class B U.S.A. 51-70-1, Finish 22.02, Class B Navy Aeronautical M-364 U.S.A. 72-53 (See An-F-20)
...es such as pistons, piston ...ylinder liners, camshafts, ...shafts, rocker arms, etc. ...apon components. Hardware	MIL-C-16232 U.S.A. 52-0-2, Type II, Class A U.S.A. 51-70-1, Finish 22.02 Class A Navy Aeronautical M-364 U.S.A. 72-53 (See AN-F-20)
...lls for cold forming, heavy ...s; tubing for forming or draw- ...etc.	———
...ucts of similar design such as ...rts, wall tile, signs, washing ...etc; aircraft and aircraft ...s (rocket launchers), helmets, ...clothes dryers, clothesline, ...etc., aluminum strip or sheet	MIL-C-5541 (See also QPL-5541-1) MIL-S-5002 AN-F-20 U.S. Navord O.S. 675 16 E4 (Ships) AN-C-170 (See MIL-C-5541) U.S.A. 72-53 (See AN-F-20)
...coatings; zinc or cadmium ...r components; hot dip galvan- ...alvanneal; signs; siding; ...mized truck bodies; etc.	QQ-P-416 RR-C-82 JAN-F-495 AN-F-20 U.S.N. Appendix 6 U.S.A. 72-53 (See AN-F-20)

CHEMICALS ACP PROCESSES

WRITE FOR DESCRIPTIVE FOLDERS ON THE ABOVE CHEMICALS AND FOR INFORMATION ON YOUR OWN METAL PROTECTION PROBLEMS

CHEMICALS ACP PROCESSES

to the man who wants

UNBIASED ADVICE *on* MOLDING MATERIALS

● What molding material is *best*? Which is *cheapest*? That's where American Hard Rubber Company serves so well—and so often. We can select from literally hundreds of hard rubber compounds... many thermoplastics . . . and several unusual materials like Ace-Tex or Ace-Hide shown below . . . plus complete facilities for molding, extruding, machining, finishing, etc. Ask our advice. It's impartial. It's free.

HARD RUBBER — Many Ace compounds offer tensiles to 10,000 psi, excellent chemical resistance, moisture absorption as low as 0.04%, power factor as low as 0.6% . . . molded parts, sheets, rods, tubes, linings, coverings, etc.

HARD RUBBER GUN PLATE

ACE PARLAN® — Tough cellulose acetate-butyrate, high impact up to 9.4 Izod. Good for housings, control wheels, handles, etc.

PARLAN STEERING WHEEL

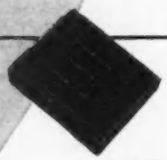
ACE PARIAN® — Polyethylene; tensile to 3,000 psi; dielectric to 700 v/mil, unaffected by most acids, alkalies and salts. Good for chemical, electrical parts.

PARIAN CHEMICAL VALVE

ACE-HIDE® — New rubber-base material is practically indestructible. Impact strength to 10.0 Izod. Chemical resistant. Good for parts that take beating, like acid pails, golf-bag tops, chair arms, etc.

ACE-HIDE CHAIR ARM PAD

ACE-TEX® — Not rubber, not plastic, but a pyrobituminous molding material. Relatively low strength, high chemical resistance. Used in auto battery cases, containers, etc.

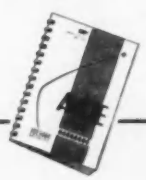


ACE-TEX TRAY

American Hard Rubber Company

93 WORTH STREET • NEW YORK 13, N. Y.

SEND FOR FREE ACE HARD RUBBER AND PLASTICS HANDBOOK



Sans, Souci

Ad Libbing by the Editor

George Low, general roadmaster of the Western Rail Road told me this. When Big-Frank came to this country as a fourteen year old boy he got a job in a stone quarry. That was about 1890. His particular chore was to drive the team of horses that pulled the industrial rail cars over the track. The cars were loaded heavily with stone, the tracks were anything but straight and the ground wasn't level.

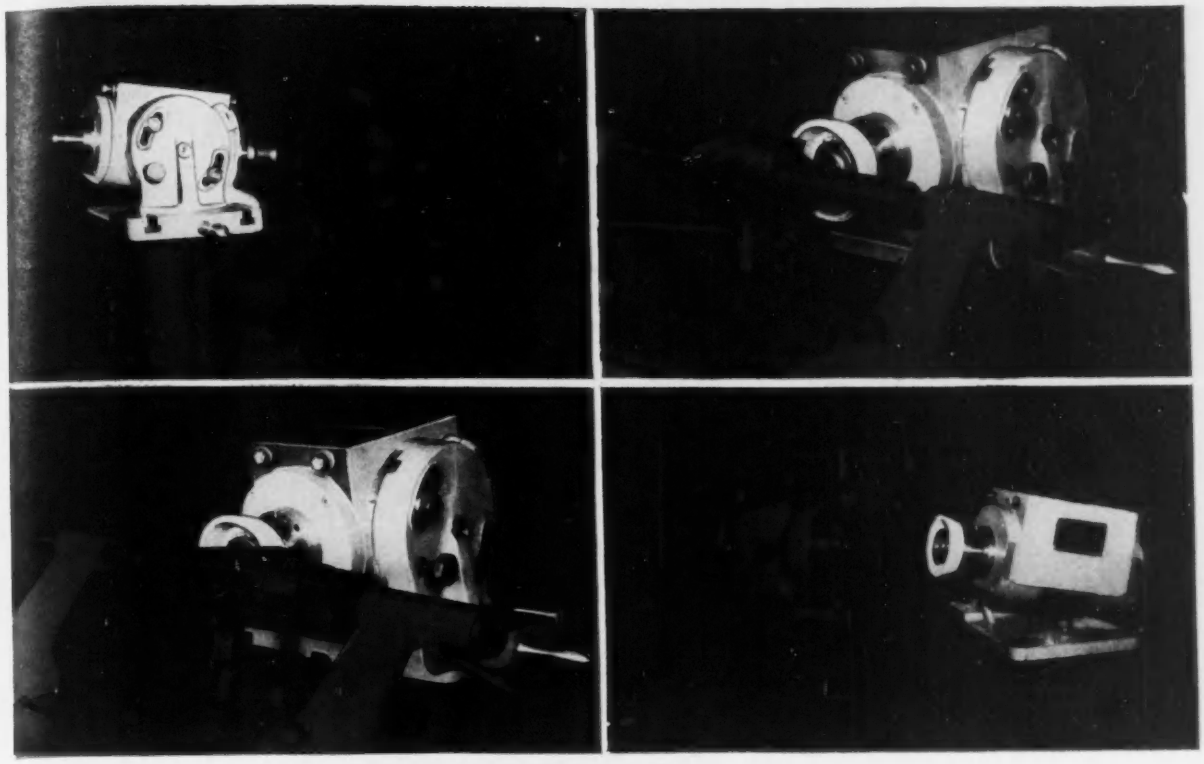
Little Big-Frank loved the horses. He would feed them with extra lumps of sugar out of his lunch box. Often he shared his sweet crackers with the horses. And naturally the horses loved Frank. And little Frank was also considerate of the horses. For example, at one place the track went down hill and then up hill quite steeply for a short distance. So in going down hill Frank urged the horses to run, he running after them with the reins in his hands. In this way it was easy for the horses to get the heavily loaded cars over the top of the hill.

Even as a boy Big-Frank had his eyes on the dollar. All around him in the quarry were men making seven and eight dollars per week and he was getting only four. In view of the fact that he was doing a job that was usually done by a man, he figured that he ought to be paid at least a little bit more than half a man's wages. So he went to his boss and asked for a dollar a week raise. The boss simply laughed at him and promptly fired him. In 1890, that was the custom.

The next morning little Frank came to the quarry and sat at the top of the bank that surrounded it. Perhaps he expected what happened. The boss had given the job of driving the horses to a man who was lazy. Instead of letting the horses run on the down hill stretch he held them back because he didn't want to run. When the horses got to the short steep hill they were unable to pull the cars up it. The lazy man then used his switch. The horses became frightened, broke their traces and ran away. Young Frank came bounding down the steep bank screaming all kinds of invectives at the driver of the horses and bawled him out thoroughly for having used the whip. The cars were off the track, some were dumped over. About that time the foreman came up and decided he had better rehire "the kid" and pay him a dollar more.

When I was told this story it oc-

LOOK AT THE NEW AND BETTER WAY TO GRIND TOOLS



THE NEW POPE SUPER PRECISION
1 HP, 3600 RPM MOTORIZED TOOL AND CUTTER GRINDER HEAD

With Angular Adjustment In A Vertical Plane

Specify this new and better motorized Spindle on your next tool and cutter grinder.

Replace less effective, less versatile heads on your present grinders.

This totally enclosed POPE Spindle with sealed-in lubrication has the radial and axial rigidity to make wheels cut faster — spark out quicker.

It produces the kind of cutting edge on your tools that stands up and cuts longer.

It is easy to install.

It reduces set-up time.

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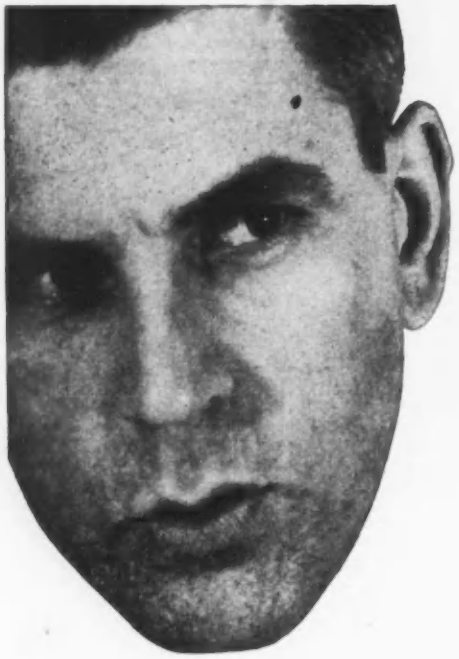


how much is bearing trouble affecting your products' reputation?

It can you know — and yet it is so easy to avoid machinery inefficiencies traceable to bearing failures. Just be sure to specify one of the MULTIROL full type roller bearing series. Each is designed for a specific kind of service and has proven ability to carry greater loads longer with more precision and less maintenance. Their dependability will help keep your machinery at its peak. Select one of the following types and write today for more details in the new McGill Bearing Catalog No. 52.

cured to me that there was one strand that ran throughout Big-Frank's life. As a boy he fed the horses sugar and cakes because he liked them. He also got to know them and thereby was able to get them to cooperate with him to make it easy going over the bumps, for both him and the horses. That is exactly what he did later in life in his relations with people. He was always a most genial host and his greatest delight was to get several of his friends and take them out to a sumptuous meal. He entertained because he liked to entertain. He liked people and in entertaining them he got to know the people and they got to know him. And just like little Big-Frank drove and treated the quarry horses, so he drove and treated the men under him. And they liked him because he treated them well and was always considerate of them and made their jobs as easy as possible.

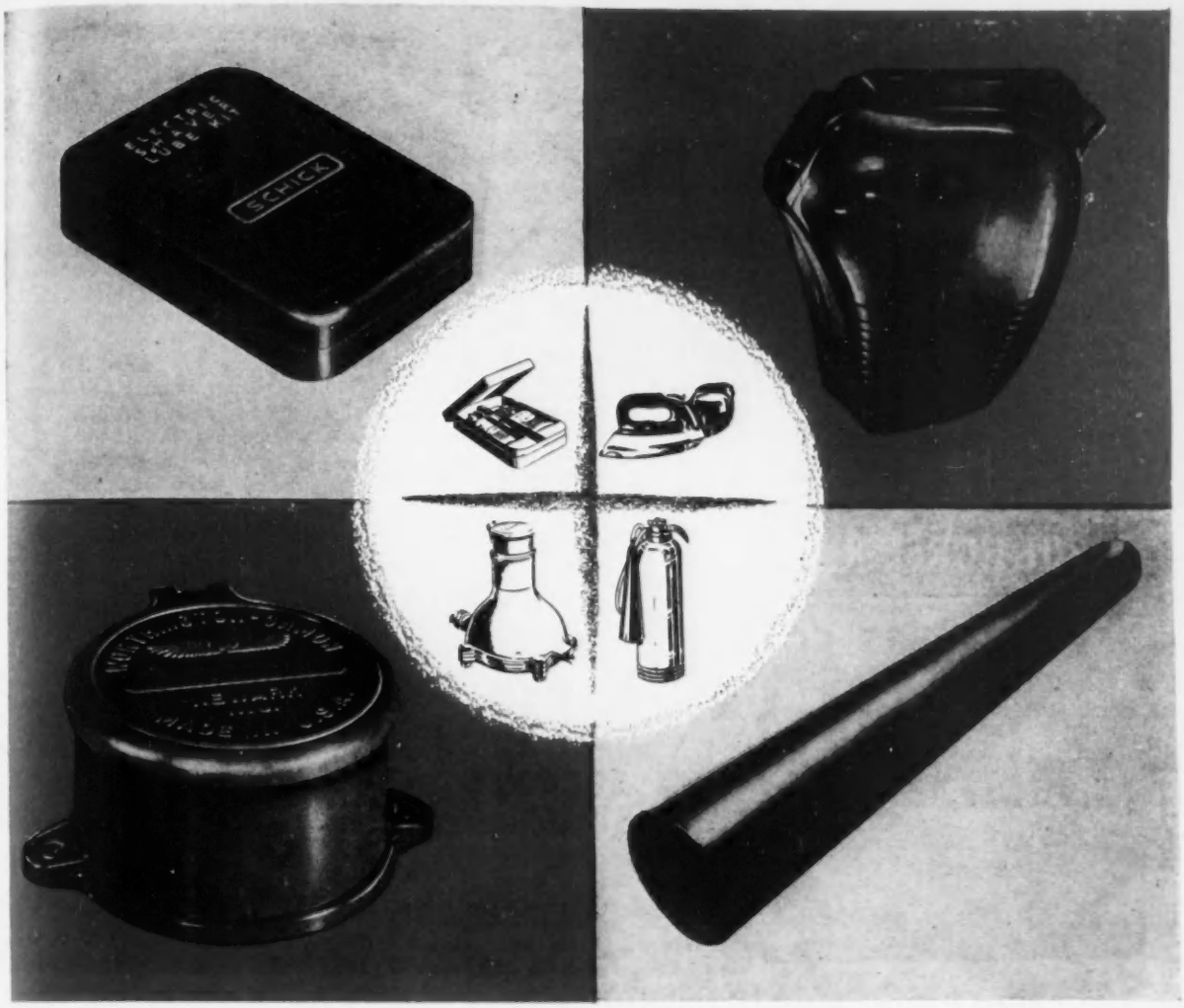
How Chu Fuh Did It

Chimin Chu-Fuh is the kind of a man one can never forget. Briefly, Chu-Fuh attended missionary schools in China and in 1910 he took the Boxer Scholarship examinations and came out second high. He then entered Lehigh University as a student in civil engineering in September 1910. He sat next to me at the table in the Commons and that is how I got to know him quite well.

His record at Lehigh gives a pretty good picture of the kind of a fellow he was. He covered the four year course in three years. He was elected to Tau Beta Pi, and was also elected a member of Phi Beta Kappa, one of the first engineering students to have received that honor. In competition with five American boys he won first prize in an oratorical contest. He was the top of his class. He was highly respected by all of the students and had a wonderful sense of humor. But perhaps most amazing was his mental ability. He always reminded me of that quotation from Goldsmith's Deserted Village, "And more and more the wonder grew that one small head could hold all he knew." Only about five feet five inches tall and weighing probably less than one hundred and twenty pounds, this quotation from the Deserted Village fitted Chu-Fuh quite well.

One day I came across an extremely interesting plane geometry problem but a rather vexing one because I wasn't able to solve it. It looked extremely simple but proved to be extremely difficult. Even some of the profs found it hard to do.

One night I was over in Chu-Fuh's



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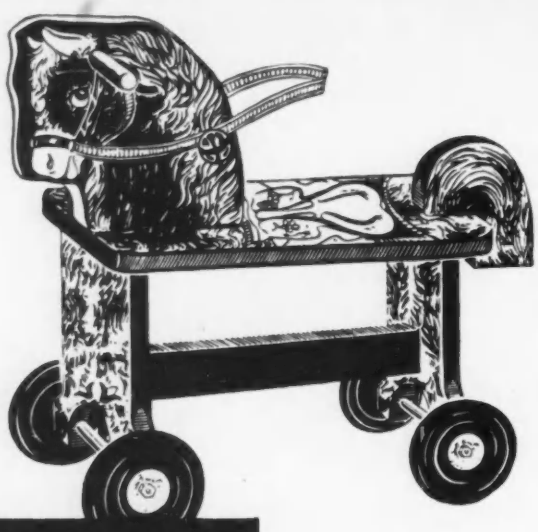

#301 HORSE RIDER

DISCOVERS CONTINENTAL'S

HOLTITE

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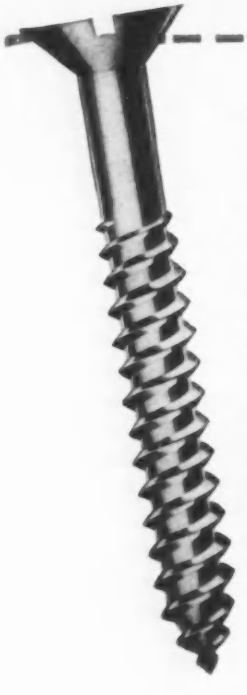

The Gong Bell Mfg. Co. has been making quality toys and bells in East Hampton, Connecticut, since 1866. One of the most popular items in the Gong Bell line is the #301 Horse Rider.

But, until recently when Gong Bell "discovered" Continental's new Holtite "TWINfast" Wood Screws, assembly was slow and painstaking. Since then costly assembly time has been slashed, the assembled unit substantially strengthened and the toy lasts longer. Now even the roughest young Hop-A-Long Cassidy enjoys a smoother ride because Holtite "TWINfast" Screws are doing a better job of holding the unit together.

Time savings and improved product quality like this are typical of Continental screw fasteners and screw fastening methods. By examining your own problems in production fastening and presenting them to us, we may be able to help you more than you think. Why not get in touch with us now? Continental Screw Company, New Bedford, Mass. Remember,

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HOLTITE *Engineered* FASTENINGS

CONTINENTAL SCREW COMPANY INC. ★ 1904 ★ TRADE MARK

room. He was sitting on the edge of the bed taking his shoes off when I gave him the problem. I can still see him looking at me with his Oriental eyes wide open and saying, "That is a very difficult problem." I asked him how did he know it was difficult, had he seen it before? He laughed and said, "Ah no, but it is difficult because it sounds so simple. If it were as simple as it sounds it would be no problem." As I was going through the hall on my way back to my room the light coming through the transom of Chu-Fuh's room went out. Obviously he had gone to bed.

Chu-Fuh had breakfast every morning at seven o'clock, just as soon as the Commons opened. Sleepy headed me usually came around about 7:30. The next morning when I got to breakfast there was a little slip of paper under my plate. It was the solution to the problem. As a matter of fact, Chu-Fuh had worked out the two possible solutions along with the proof. I was amazed. Here was a problem that had stumped the professors and Chu-Fuh had solved it between the time that he had taken his shoes off to go to bed and before breakfast next morning. When I saw Chu-Fuh at lunch I asked him whether he had gotten up again to solve this problem. He laughed and said, "Oh no." I said to him, "Well how did you come to solve it so quickly?" He said, "Well I lay in bed and I imagined that I had succeeded in making the required construction. Then I worked backwards to figure out how I would have to go to reach the goal. As soon as I did that the answer was obvious."

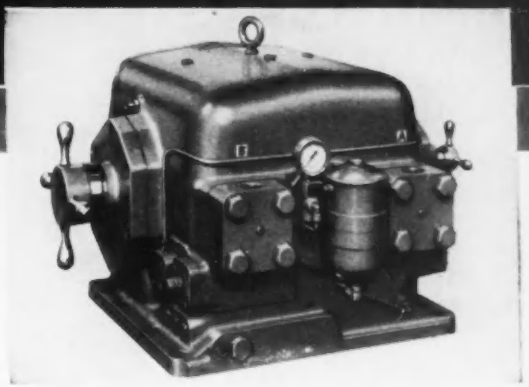
To Chu-Fuh the answer was obvious. I don't believe it would have been obvious to me or the average person. However Chu-Fuh had a point. Often we get stumped on a problem in the design of a mechanism or construction. The going is rough and we stumble along, only too frequently missing the goal. If we were to work backwards from the desired end point to the starting point we would at least establish an approximation which might serve us in pointing the way to a complete solution. I have tried it quite a number of times and it often works nicely. And every time I try it I think of Chimin Chu-Fuh.

Sheets in Bunkhouses

On another night when I dropped in to chat with George Low, general road master of the Western, he got on the subject of labor camps along the railroad. Back in the old days the custom was for the railroad to provide cars with bunks built into them for the

OILGEAR picked by engineers for new Monongahela River Lock

Photo courtesy Corps of Engineers, US Army



Oilgear Two-way Variable Delivery Pump with Electro-hydraulic Three-position Remote Control.

This versatile fluid power also used in McNary Dam and Bayou Boeuf Locks

The problem of selecting the power to operate the lock gates, butterfly valves and capstans in the new Monongahela River Lock was to provide the speed of operation, the capacity and the dependability that would keep the rapidly growing volume of shipping on the move. The river at this point now handles millions of tons more annually than Panama.

Certainly, in the fact that Oilgear Fluid Power equipment was selected for this lock, as well as for those at McNary Dam in Oregon, and at Bayou Boeuf in Louisiana, is evidence of the repute in which Oilgear is held.

But we are inclined to stress the *versatility* of Oilgear Fluid Power . . . its applicability to a wide range of needs ranging from the impressive capacity required for lock operation . . . to the delicate and assured precision, controllability and accuracy required in printing on flimsy cellophane . . . and to the middle ground of industry where production must always be increased and always kept on the move.

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With Oilgear Fluid Power available in pump and cylinder for straight line motion, or in pump and motor or integrated transmission for rotary motion or reduction of ratio, you have a power source and method applicable to any need. In addition, you gain ability to vary speed or power steplessly in an extremely broad ratio. You can have power that does not move but simply holds a member under constant pressure. You can have speed that clings closely to the changing viscosity of a beaten mass... or power that forms giant airplane fuselages and wings.

Whatever your problem, it deserves the opportunity to be matched with Oilgear versatility for a better solution. It will cost you nothing to investigate. It may show you a tremendous gain. THE OILGEAR COMPANY, 1571 W. Pierce St., Milwaukee 4, Wisconsin.

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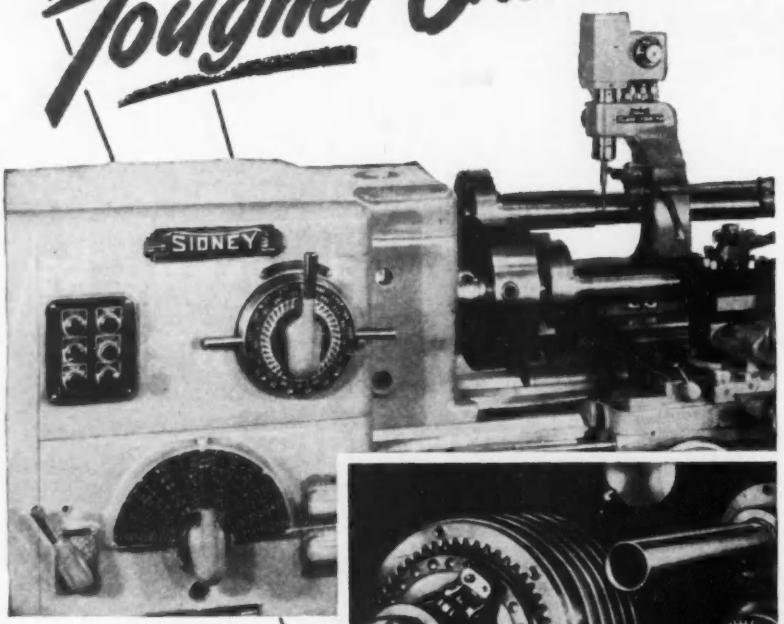

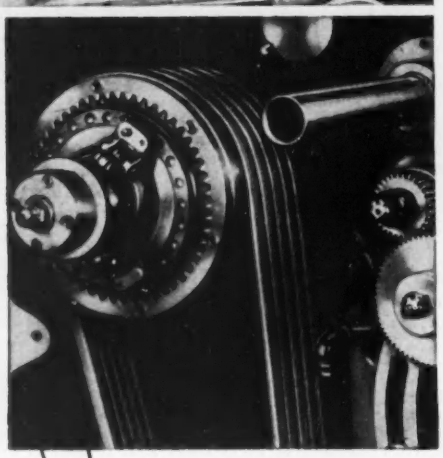

Clutches get tough treatment in such high speed work as performed by the Sidney 32 in. Model 16 heavy duty lathe. Driving clutch is 8" Twin Disc Model CL, rated at 40.7 hp.

As designers come up with new machine performance achievements, they must have components that will stand the *new* gaff.

As "speed feed per minute" is stepped up with improved cutting tools, machine tool designers have to re-examine the ability of drive units to "take it." They find, of course, that Twin Disc's Machine Tool Clutches have the necessary reserve to deliver, unfailingly, day after day performance in the most severe clutching service.

That, plus Twin Disc's unmatched service facilities, 8 Factory Branches and 60 Parts Stations, is why you find Twin Disc Clutches in the leading machine tools. Get the story in Bulletins 134-A and 120-D.

Built for a long life . . .
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track laborers to sleep in. There was also a kitchen car and a mess car. In the old days with each bunk went a blanket, usually dirty and filthy. There were no mattresses and there were no sheets. The railroad charged the men a dollar a day for the three meals and the lodging. The beds were hard and the food was coarse—and the men didn't like it.

Not long after Big-Frank got the job of supervising the laborers on the railroad he appealed to the railroad officials to provide mattresses, sheets, pillows and pillow slips for the bunkhouses. He had everything figured out and he assured the railroad official that with the better living conditions the men would produce more. His idea was not accepted. Big-Frank then guaranteed that the value of the added production would be several times the cost of the additional bedding and keeping it clean. But the railroad brass shook their heads sideways. Big-Frank then suggested that they equip one camp complete with sheets, pillows, pillow slips and mattresses and see if the production wouldn't increase. This sounded sensible to the president of the road. Big-Frank was told to try it and if the trial camp proved that sheets and pillow slips gave bigger production the railroad would put them in all the bunk houses.

Big-Frank invariably got what he went after and he was never dumb about the way he did things. He selected the best camp along the railroad. He then switched the men until he had all of the best men in each camp transferred to the test camp. After the men had worked there for about a week Big-Frank put in the mattresses, sheets, pillows and pillow slips. Then he called the gang together and gave them a talk.

"Men", he said, "You fellows are going to decide whether or not you are always going to have nice clean beds like you have now or whether you are going to go back to the hard boards and the dirty blankets. If you fellows show by the amount of work you do that you appreciate nice white clean beds you will have them all the time and every camp on the railroad will have them."

With that inspiration the gang went out and hung up all time records. A month later the railroad brass decided to equip all of the camps along the Western Railroad with sheets and mattresses. It didn't take long for the news to be noised around and the Western Railroad was deluged with men who wanted to work on their track gangs. Western got the pick of the best track workers.—G.F.N.

Customer Reports:

"We Switched to Continuous-Cast Bronzes... Rejects Now Negligible...No Field Failures"

JACUZZI BROS., INC., Richmond, Calif., had heavy losses due to rejects of pump bearings made from sand-cast bronze.

"Since switching to ASARCO Continuous-Cast Bronzes (75% Cu, 5% Sn, 20% Pb, and 83% Cu, 7% Sn, 7% Pb, 3% Zn), REJECTS ARE NEGLIGIBLE, and there have been no field failures," says Mr. R. Delahay, Jacuzzi production engineer.

Here's why ASARCO Continuous-Cast Bronzes cut rejects: porosity, dirt, hard and soft spots are non-existent; alloy constituents are uniformly distributed. Also, dimensions are held to close tolerances: +0.004" to −0.006" on O.D., and tube concentricities to within 1.5% of wall thickness. Fatigue and impact characteristics are up to 100% better than those of sand-cast or permanent mold stock; tensile and yield strengths are appreciably higher. All stock for machining is Medart-straightened.

ASARCO Continuous-Cast Bronzes are available in rods, tubes and shapes . . . in many alloys, made to your specific requirements if necessary. Lengths are *cut to the exact size you want* up to 12′ (standard) or 20′ by special arrangement.

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PITCHLIGN

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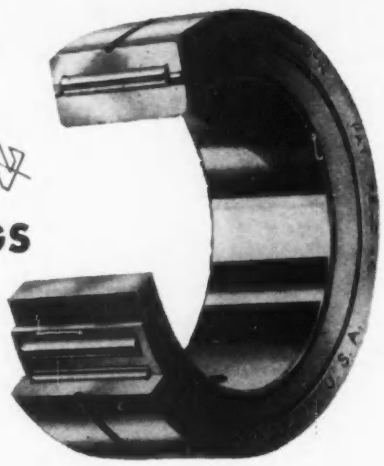

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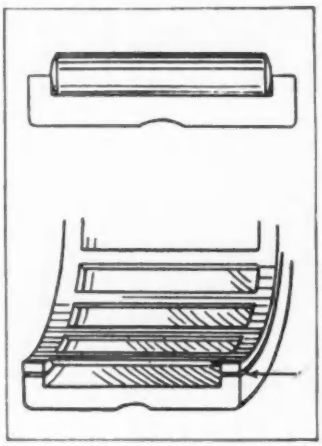

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ENGINEERING ABSTRACTS

Die Casting Design

Abstracted from "Good Design Can Cut Die Casting Costs," by W. M. Halliday, "The Iron Age," June 5, 1952.

PRESSURE DIE CASTINGS vary only slightly from parts made by other methods, can often be produced at considerable savings in costs.

Best results and economies are possible where the die casting engineer and die designer have some latitude in duplicating shapes, forms, features, sizes and tolerances.

Full advantage of the die casting method may best be obtained where parts are designed to meet the limitations and possibilities of die casting and of die construction.

The importance of this approach is illustrated by the decorative beading, Fig. 1, in zinc-base alloy, for use with a plastic molded car bezel. This die casting replaced hollow light gage aluminum pressing. A die cast part was selected because of the ability to cast-on critical rivets and provide a component capable of withstanding handling during polishing, electroplating, and mounting.

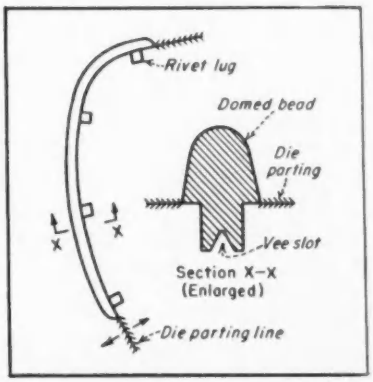
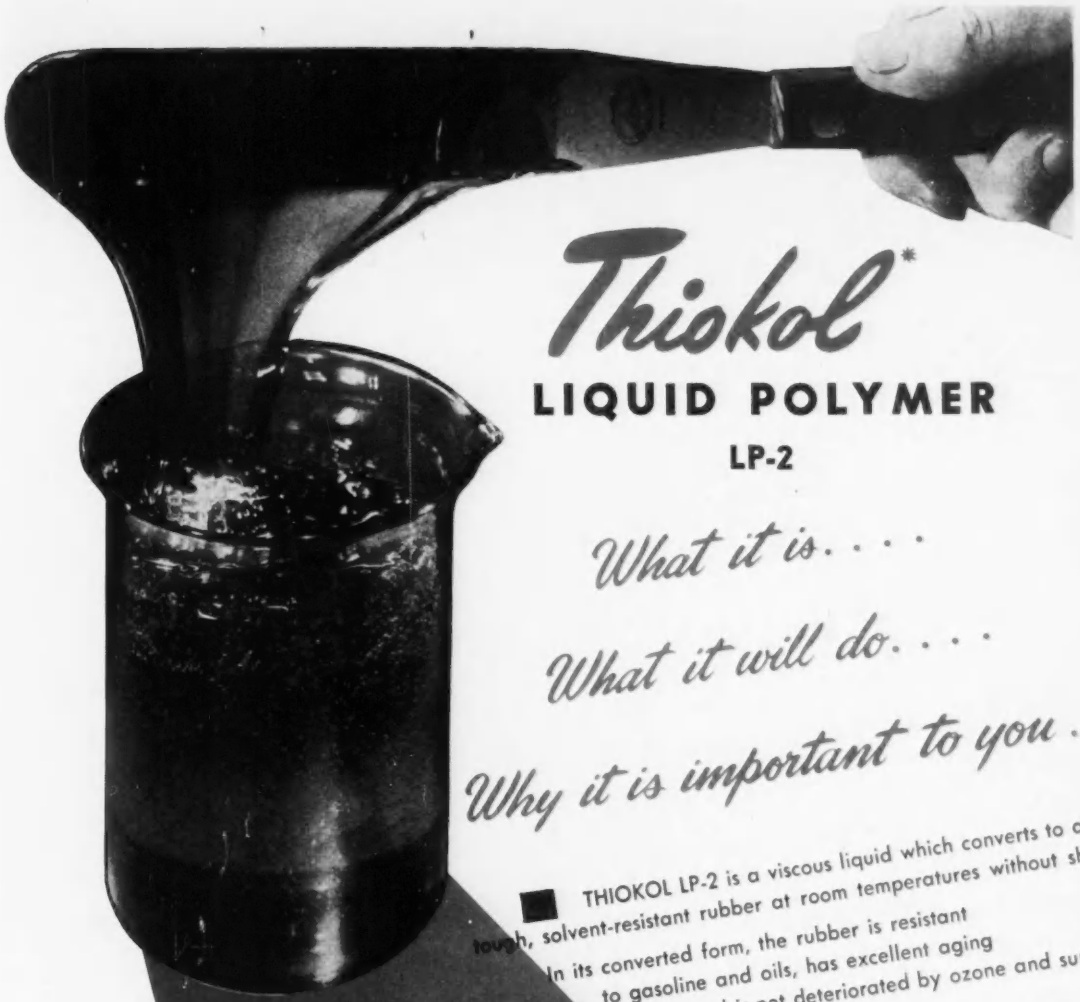


FIG. 1—Decorative zinc alloy beading replaced light gage aluminum pressing, gave stronger, cheaper part.

The casting comprises a long strip, U-shape in cross-section and curved along its entire length to match the camber of the bezel.

Four lugs, elliptical in cross-section were to be cast on the underside of each beading. A V-notch was to be formed in the top of each lug.

The die for this casting was costly because of machining difficulties in the awkwardly curved parting joint, the need for a closed seal thereon, and



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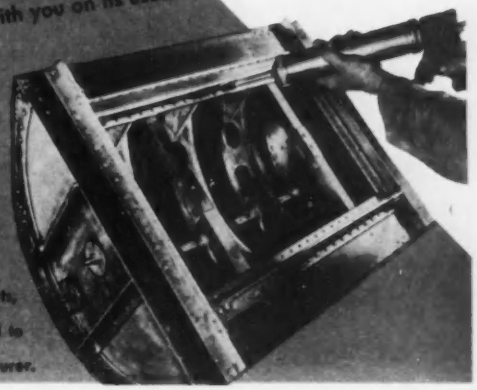
■ Technical personnel of the Thiokol Corporation are ready to consult with you on its uses.



Thiokol Corporation supplies LP-2 ONLY as a raw material. If your normal source of supply is unable to furnish your requirements, the THIOKOL Corporation will be glad to suggest a manufacturer.

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- *Every Modern Finishing Service*

Detroit Ave. at W. 93rd St., Cleveland 2, Ohio

the location of elliptical cavities for rivet lugs.

The die was slow in action and difficult to operate. Because of the inclination of the lugs relative to normal direction of die opening, these portions deformed and misaligned to each other due to lengthwise shrinkage before parts could be ejected.

Heavy flash was also present on the sides of the cast beadings, due to poor sealing on curved die parting joint. High breakage occurred with the slender V-shaped core plugs because of heavy contraction strains.

The 4-cavity die produced only six castings per minute. It was decided to cast the beadings straight and bend them to shape. Bending tests indicated the parts could be bent quickly and safely while still hot by a hardwood fixture.

A new die with a flat parting joint eliminated several difficulties of the original die. Lug cavities, formed at right angles to the parting joint and lugs were not distorted. Less strain was imposed on cores. Flash was negligible due to the closer seal on flat parting joint surfaces. Ejection of headings was quicker, and safer.

The new 4-cavity designs generally mean reduced costs, on both castings and lies, together with quicker working and greater durability.

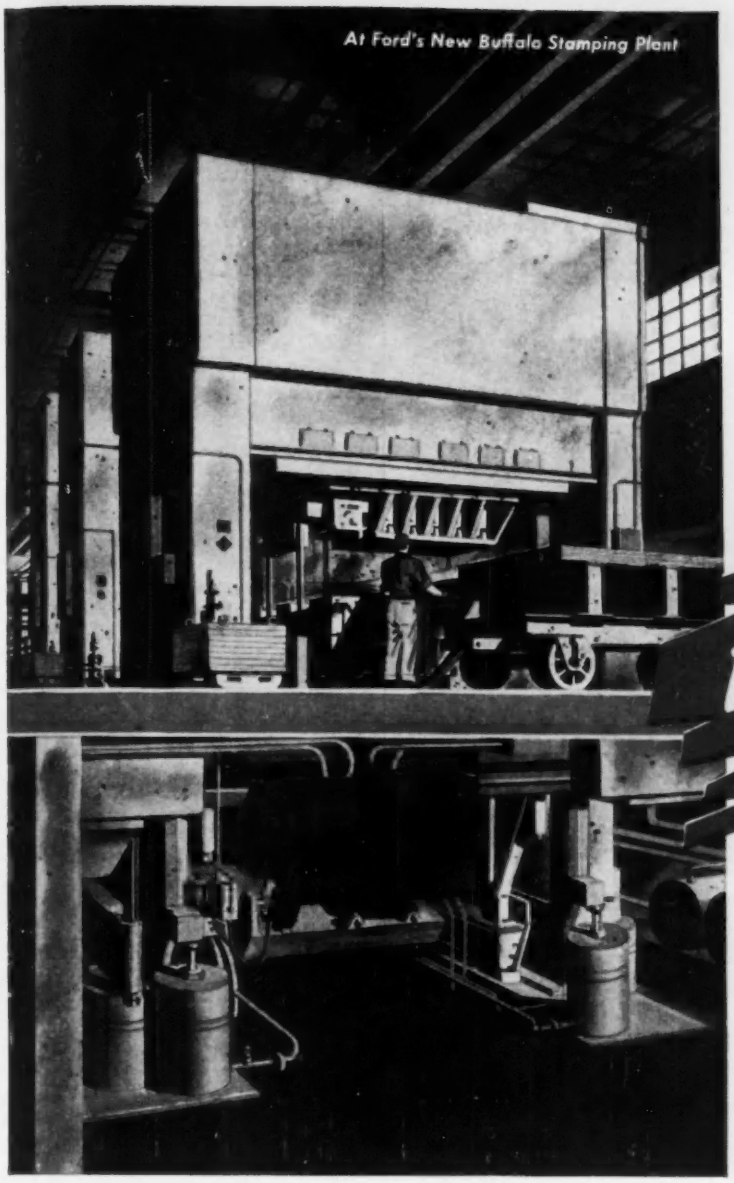
Quantity of parts to be made also influence cost and quality. Where die costs must be amortized over a small quantity, say 10,000 parts, the die caster must evolve the simplest and least expensive die capable of making this many parts.

Such a die will usually be of the single impression type, unfitted for long runs. Indications should be given the die caster at the outset as to possibilities regarding future quantities. Provisions may be made for inserting additional cavities at a later date if production has to be stepped-up. Better die materials may be used to insure longer working life.

Die costs are closely related to part design and length of tool life. A complex die, due to wear, distortion of die elements, and fatigue of materials due to heat exposure may have a working life of 40,000 shots, even with the low melting point alloys. A simpler die may produce upwards of 250,000 shots in low melting point alloy before showing appreciable signs of wear.

For high melting point alloys, hardened heat-resisting tough die steels are recommended despite higher cost. maintenance requirements will be lower.

Very small holes of great depth or awkward inclination to main die part-



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help set

WORLD PRODUCTION RECORD

on Triple-Action Presses

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Adjustable speeds by the Reliance V★S System have answered the challenge of establishing and maintaining record production from mammoth, triple-action automobile body presses at Ford Motor Company's new Buffalo Stamping Plant. Flywheel and clutch are eliminated. Starting, stopping and reversing are accomplished electrically. Adjustable inching speed is available as required from direct-connected, 500-horsepower Reliance motors—the largest ever placed on such presses. Other important advantages of these drives by Reliance include the saving of a substantial amount of steel that was formerly scrapped and a reduction in die replacement costs. Contact your nearest Reliance Sales Representative for further facts on drives engineered by Reliance—for presses or any other type of production machinery.

RELIANCE V★S SYSTEM®

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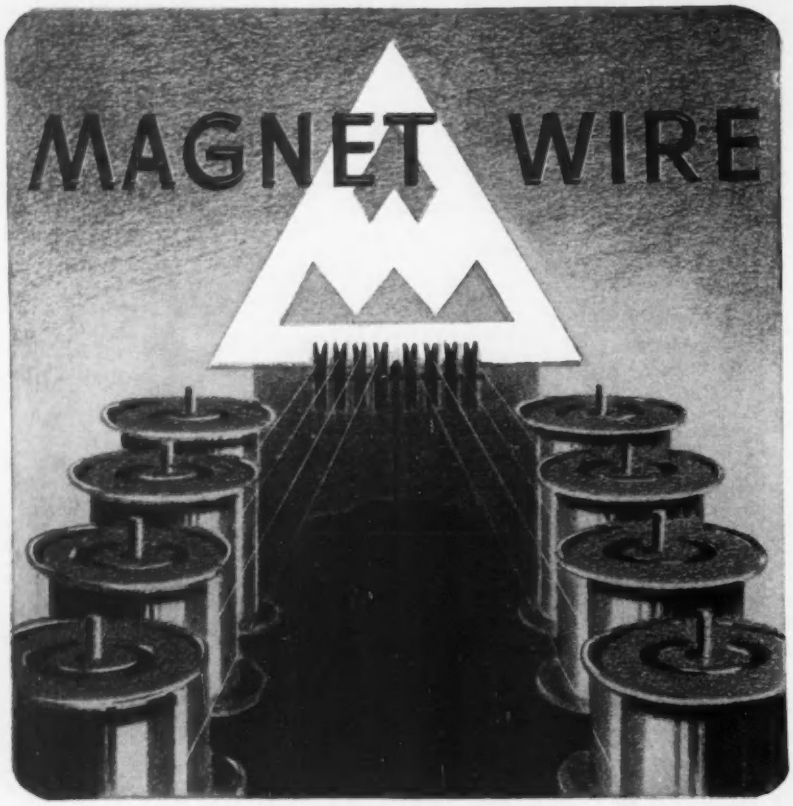
When you cannot see inside the product



it pays to look "inside" the manufacturer

Magnet wire cannot be judged by externals. Hidden manufacturing variables quickly show up in the winding room . . . on the test rack . . . or out in the field.

Producing magnet wire of much better than usual quality . . . especially in the finer gauges . . . is Wheeler's specialty. We invite users of this product . . . whether large or small . . . to LOOK INSIDE WHEELER and see for themselves what we have to offer. Briefly, here is what you will find:

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Complete specialized enameling department.

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ing should be avoided. They require delicate cores, mounted to slide, rotate or collapse to allow for ejection of casting. They are fragile and involve high maintenance, production delays and extra cost. Likewise part shapes necessitating irregular parting joints lying in two or more planes will often lead to faults and wear in the die.

Die quality affects accuracy and surface finish of castings. When planning a die casting the designer should be guided by several rules.

Split steel dies require at least one main parting joint to seal within 0.001 in. on a band $\frac{3}{4}$ in. wide around edges of cavities, runners, gates, and air vents. Dies should split to permit easy machining of cavities and ejection of finished casting. Castings tend to shrink away from cavity walls, and grip upon hole-forming cores.

Parting joints should be flat, straight and in a single plane. Irregular parting joints are difficult to machine and slow die operation.

Cores may be integral with cavity walls, or separate members mounted in the die to interject into the cavity. Cores, fixed or movable, may rotate, slide or rock in the die. Movable cores require mechanical actuation. Most convenient mechanism permits cores to be worked automatically by normal opening movements of the die.

Projections, undercuts and similar formations athwart the line of die opening and wider than the cavity at the parting joint retard ejection.

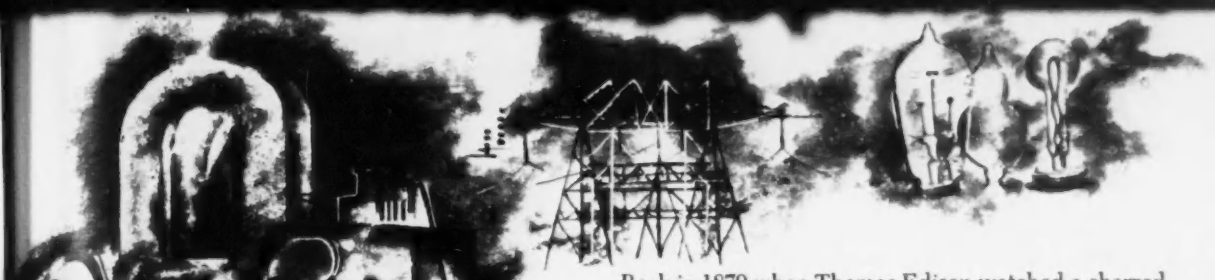
To facilitate ejection, draft must be provided on cavity walls, and sides of cores. Minimum practicable draft will be about 1 deg per side, except with holes of large diameter and very short length. The greater the taper allowed the simpler will be ejection. Such taper also reduces the delay between injection and ejection, thus dimensional tolerances can be controlled more easily to offset the effects of normal shrinkage.

Ejection may be accomplished by movable stripping cores in a slide or by rods which push the casting off stationary cores. This latter method, generally most effective from die construction and operation angles, entails some collar flash on sides of casting where rods impinge on the part.

Size, number and location of ejector rods are important to equalize pressure on the part when stripping.

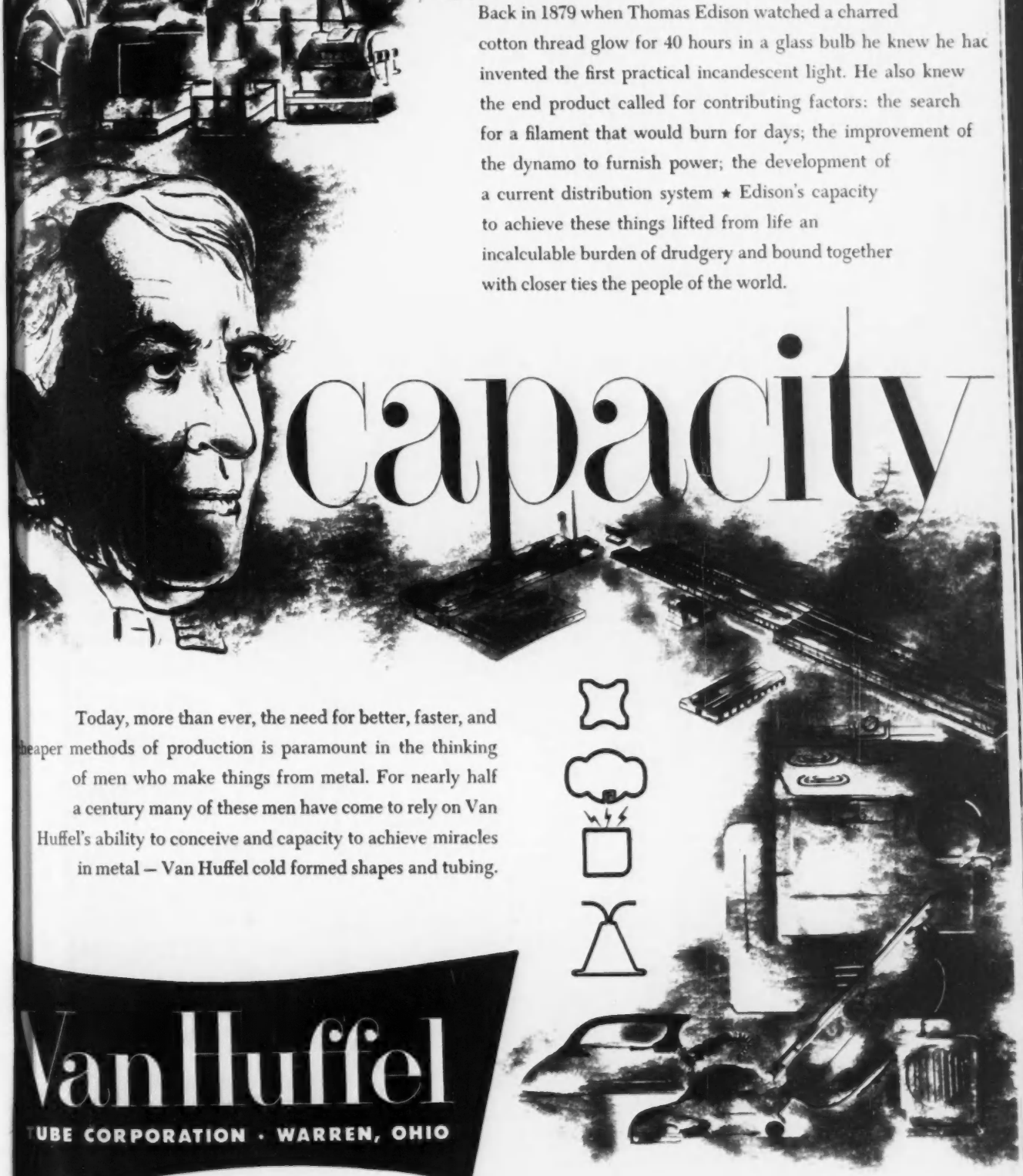
Adequate venting channels must be provided—usually along main parting joint surfaces to ensure proper fill of the cavity and avoid porosity.

Physical properties of the part are often influenced by the gating used. Intricate, large, or extensively cored cavities may offer gating problems



Back in 1879 when Thomas Edison watched a charred cotton thread glow for 40 hours in a glass bulb he knew he had invented the first practical incandescent light. He also knew the end product called for contributing factors: the search for a filament that would burn for days; the improvement of the dynamo to furnish power; the development of a current distribution system ★ Edison's capacity to achieve these things lifted from life an incalculable burden of drudgery and bound together with closer ties the people of the world.

capacity



Today, more than ever, the need for better, faster, and cheaper methods of production is paramount in the thinking of men who make things from metal. For nearly half a century many of these men have come to rely on Van Huffel's ability to conceive and capacity to achieve miracles in metal — Van Huffel cold formed shapes and tubing.

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which can only be overcome by modifications of part design.

Thin wall sections as small as 0.020 in. for zinc-base alloy, and 0.055 in. for high melting point alloys can be readily cast. Thick sections, tend to be porous and weak. Ribs, beads, bosses and fillets at points of greatest stress can often increase strength and rigidity of casting walls without appreciably adding to the amount of metal used.

Ribs, beads, fluting, filigree impressions, lettering and similar ornamentation can be cast-on without difficulty but should be in raised characters on sides of component. Obverse impressions require costly machining. Fine tolerances cost more.

Fine tolerances generally involve additional die costs and greater care in its use. Dimensional accuracy will largely be conditioned by part design and accuracy of the die.

Closest accuracy is possible with low melting point alloys since better control can be obtained over normal shrinkage of cooling metal in die cavity, and expansion and contraction of the die itself.

Many designers have difficulty locating the parting joint on the part. Generally a die should be parted along the line of greatest dimension on the part. Maximum diameter of the cavity formation will lie at the parting joint surface and permit the casting to be ejected at right angles to the joint.

With most die castings, two or more parting lines will usually be available, as in A and B, Fig. 2. The simplest die parting, A, is situated across the upper open end. The exterior of the sleeve would thus be formed from a single cavity in the stationary die. A three diameter core would be mounted in the movable die half. Ejection is accomplished by withdrawing the core within the die, or using ejector rods bearing against the endface of the casting.

Flash around the open end of the casting would be easily sheared off by pressing the sleeve through a die. Surface finish would be good, with no flash lines transversely around the part.

An alternate parting method, B,

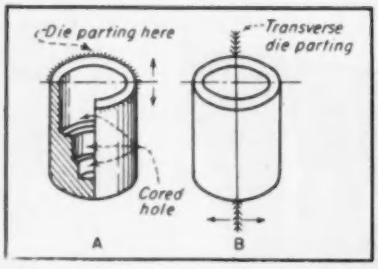
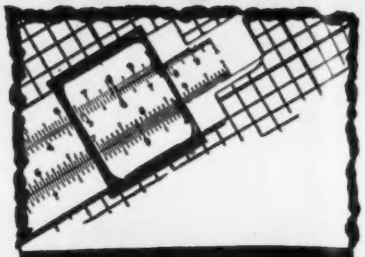


FIG. 2—Simplest die parting. A, would be located across upper open end. Middle parting, B, raises costs.



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runs transversely around the middle of the sleeve. This involves higher die costs. Two identical cavity formations are required in each die half. Such cavities must be closely matched to avoid offsetting. Flash around the middle of the casting would be more difficult to remove.

The solid core plug would have to be mounted in a vertically acting slide carried in guideways in one die half. Provisions would be required for actuating such a slide. Dimensional accuracy could not be closely maintained. Dowels would be needed to maintain alignment of die halves. Wear at these points would cause serious offsetting of the cavity formations. With the die parting shown at B multiple cavities would have to be located side by side so that all cores could be operated in one direction.

Examples of stepped, irregular and inclined die parting joints are illustrated at A, B and C of Fig. 3. At A is a part which would require a die parted in stepped fashion as shown. Flash would be extensive, much of it inaccessible.

At B of Fig. 3 is a lever requiring an irregular parting joint. Machining and accurately sealing such joint surfaces would be difficult and costly. Flash removal would be difficult.

A fulcrum lever, Fig. 3, C, has an inclined die parting. Flash occurs mainly along the lower edge of the setback inclined portion, and the center of the cylindrical base, left.

The parting line plane has to be located to allow a casting to adhere to the main core, etc. mounted in the movable die as illustrated by A and B, Fig. 4. The hollow conical casting, A, has the die parting joint situated across the bottom endface, the casting

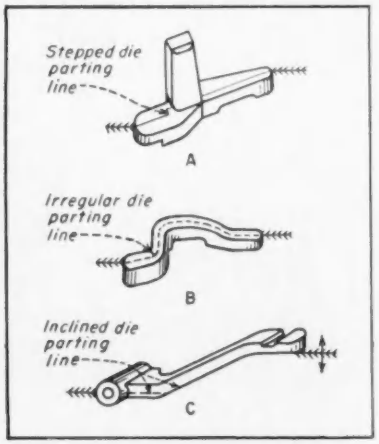
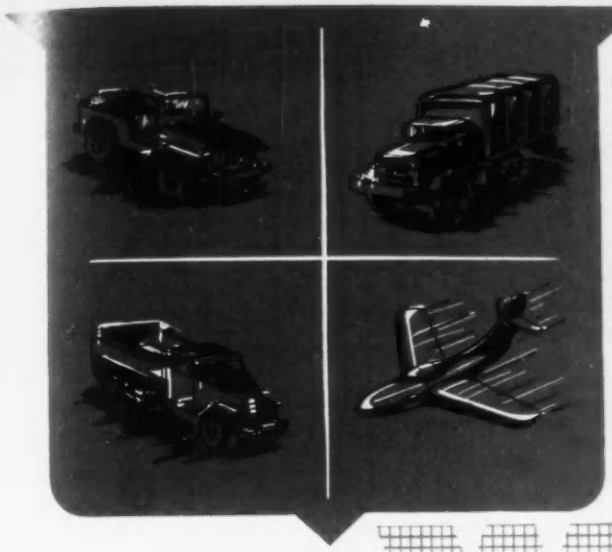


FIG. 3—Alternate parting joints are shown. Flash removal for A and B would be difficult. Dies are parted in stepped fashion, flash is extensive. Fulcrum lever at C shows an inclined die parting line.



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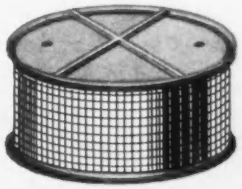

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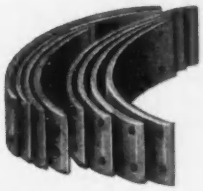

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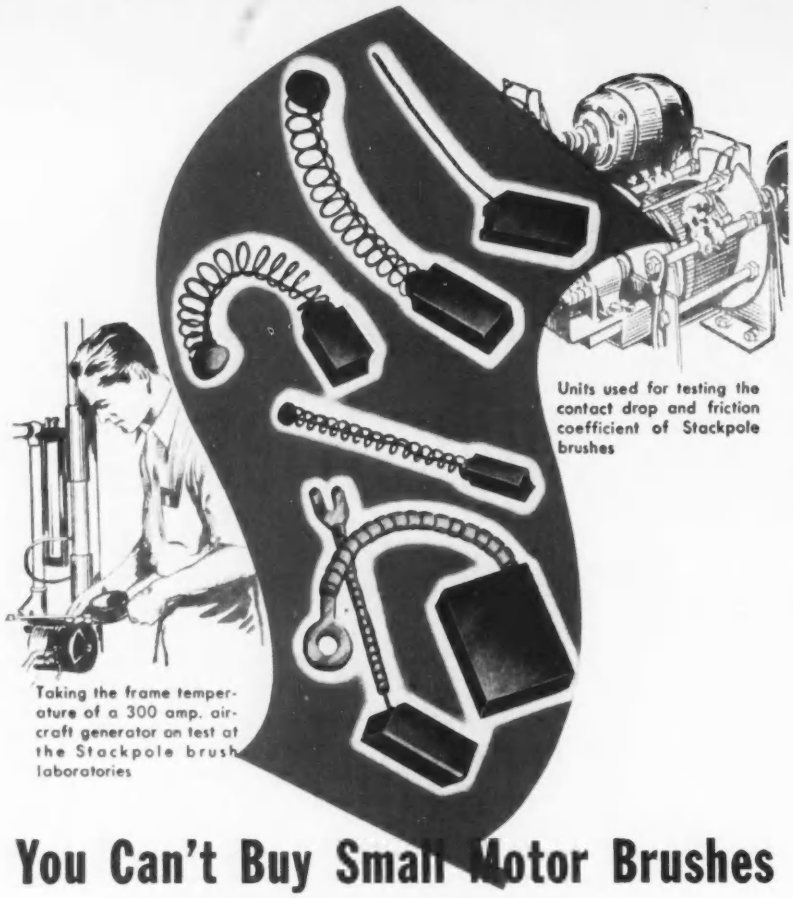

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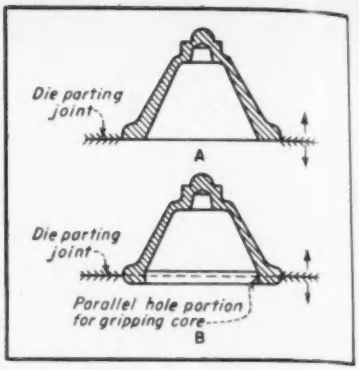


FIG. 4—Parting line must permit casting to adhere to main core in movable die. Modified design, B, is preferable. Parallel portion aids in gripping core.

being formed from a cavity in the stationary die. Such a design would not insure the casting adhering to the conical core to draw it from the cavity. The modified design shown at B is more satisfactory. Here the flange at the end is beaded. A short parallel portion is provided for gripping to the core.

Machinability

Abstracted from Machinability Theory Pays Off, by R. K. Gould, Technical & Research Div., the Texas Co., N. Y., "Steel" August 18, 1952.

MACHINABILITY, although one of the most widely used words throughout the metal cutting industry, defies strict definition, as it has different meanings to different people at different times. To most tool engineers, machinability connotes a combination of characteristics of a cutting operation, including (1) life of the cutting tool, (2) surface quality of the finished work, and (3) power consumed in machining a metal. The relative importance of these three factors depends on the nature of the operations, the equipment being used, and the ultimate use of the finished product.

Two fundamental physical processes are involved in all metal cutting operations: (1) A shearing process whereby the chip is formed, (2) movement of the chip up the face of the tool.

As the cutting tool advances through the workpiece, the metal, instead of being fractured on a line parallel to its surface, is actually sheared in a narrow zone starting at the cutting edge of the tool and proceeding at an oblique angle to the surface of the workpiece. This zone wherein the metal is sheared is known as the shear plane.

Once the chip is formed it slides over the face of the tool where it en-

HOW 40 COMPANIES
cut gear costs

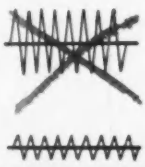
Of 50 companies checked in 23 industries, 40 told us that they adopted Cone-Drive Gears or reducers because they reduced overall costs of their products. Included are companies making conveyors; cranes, hoists and winches; machine tools; mixers, and agitators; and equipment used for agriculture, baking, chemicals, construction, food processing, foundry, laundry, leather, materials handling, mining, paper, power, rubber, steel, textiles and welding.

HOW 42 COMPANIES
cut gear size and weight

An even larger number picked Cone-Drive gears and reducers because of the savings in size and weight which they made possible. Among these were companies producing:

Aircraft
Bakery Equipment
Chemical Equipment
Construction Machinery
Conveyors
Cranes, Hoists, Winches
Food Processing Machinery
Foundry Equipment
Leather Machinery
Lumber Machinery
Machine Tools
Materials Handling
Mining Equipment
Mixers and Agitators
Paper Machinery
Plastics Machinery
Rubber Machinery
Steel Mill Equipment
Textile Machinery
Welding Equipment

HOW 17 COMPANIES
cut vibration



Since there are more teeth in contact in Cone-Drive gearing, their 'hydraulic' smoothness was a major factor in their adoption by manufacturers of: aircraft; agricultural equipment; chemical equipment; laundry equipment; machine tools; materials handling equipment; mixers and agitators; rubber machinery; steel mill equipment; textile machinery and welding equipment.

HOW 11 COMPANIES
cut no. of gears needed

The ability of Cone-Drive gears to handle large reductions efficiently on small center distances has enabled many companies to reduce the number of gears needed in their products. Among those who checked this as a major reason for specifying Cone-Drive gears and reducers were manufacturers of:

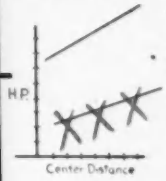
Aircraft
Chemical Equipment
Machine Tools
Materials Handling
Mining Equipment
Mixers and Agitators
Steel Mill Machinery
Textile Machinery

HOW 31 COMPANIES
boosted gear life

Cone-Drive double-enveloping gears give longer life because they distribute the load over more teeth and have a larger contact area per tooth. For the same reason maintenance requirements are also sharply reduced. Industries in which companies checked this item as a major factor in the adoption of Cone-Drive gears and reducers include:

Aircraft
Agricultural Equipment
Bakery Machinery
Chemical Equipment
Conveyors
Cranes, Hoists, Winches
Dams
Food Processing Equipment
Foundry Equipment
Leather Machinery
Lumber Machinery
Machine Tools
Materials Handling
Mining Equipment
Mixers and Agitators
Paper Machinery
Plastics Machinery
Rubber Machinery
Steel Industry
Textile Machinery
Welding Machines

HOW 42 COMPANIES
increased gear loads



The ability to increase load capacity for the same gear size—or even while REDUCING gear size—when Cone-Drive gearing is used, was a major factor in the adoption of these gears in practically every industry in which companies were checked.

Cone-Drive gears and reducers derive their advantages primarily from the fact that the gears and worms are double-enveloping. This means greater contact per tooth, more teeth in contact, better load distribution, increased capacity, longer life, lighter weight, smoother operation, higher safety factor, ability to resist shock loads, freedom from service trouble—and LOWER OVER-ALL COST.

If you would like to see the check list covering these companies, ask for Bulletin No. 101-C-222-R.

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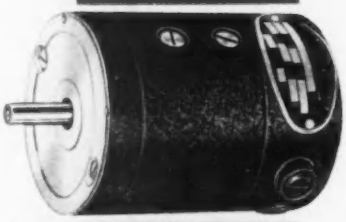

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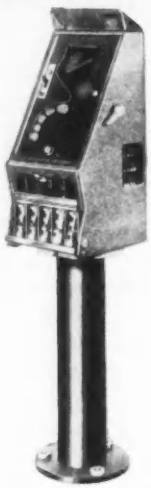

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Shaded Pole
(1/2000 to 1/15 h.p.)
Induction Types
(1/1400 to 1/4 h.p.)

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counters frictional resistance. In this region friction, wear and lubrication are of major interest.

In the region of the finished surface, the surface and subservice characteristics of the machined metals are of particular concern.

The same two physical processes—shearing the metal to form the chip and movement of the chip up the face of the tool—occur in all types of operations, whether they be turning, milling, broaching, drilling, planing, etc. The chip formed may be one of three distinct types, Table I, depending on the material being machined and the conditions under which it is formed.

Shear Angle

One of the most important factors in the cutting operation is the shear angle. This is the angle formed at the intersection of the shear plane and the direction of the cutting tool or the surface of the work material. The amount of metal deformed in the formation of the chip depends upon the size of this angle.

When the shear angle is small, path of shear is long, the amount of metal deformed is large, and the resulting chip is short and thick. Conversely, when the shear angle is large, the path of the shear is short, the amount of metal deformed is small, and the chip is long and thin. For optimum machinability a large shear angle is desirable.

Shear angle is not a constant quantity but varies over a wide range with the cutting conditions and the properties of the metal being machined. It is a measurable quantity for any given operation, but as yet cannot be predicted in advance since all of the factors involved have not been established.

Mechanical Variables

Through the use of suitable dynamometers, all the important forces and energy relationships for any given cutting operation can now be determined, making it possible to evaluate practical machining operations and machining characteristics of work materials in terms of the fundamental physical quantities.

Fundamental work along these lines has led to the discovery and isolation of three basic mechanical variables, shear strength, coefficient of friction and machining constant, which are of prime importance in any analysis concerned with controlling the geometry and forces involved in forming the chip.

From the standpoint of efficient and economical machining operations, low

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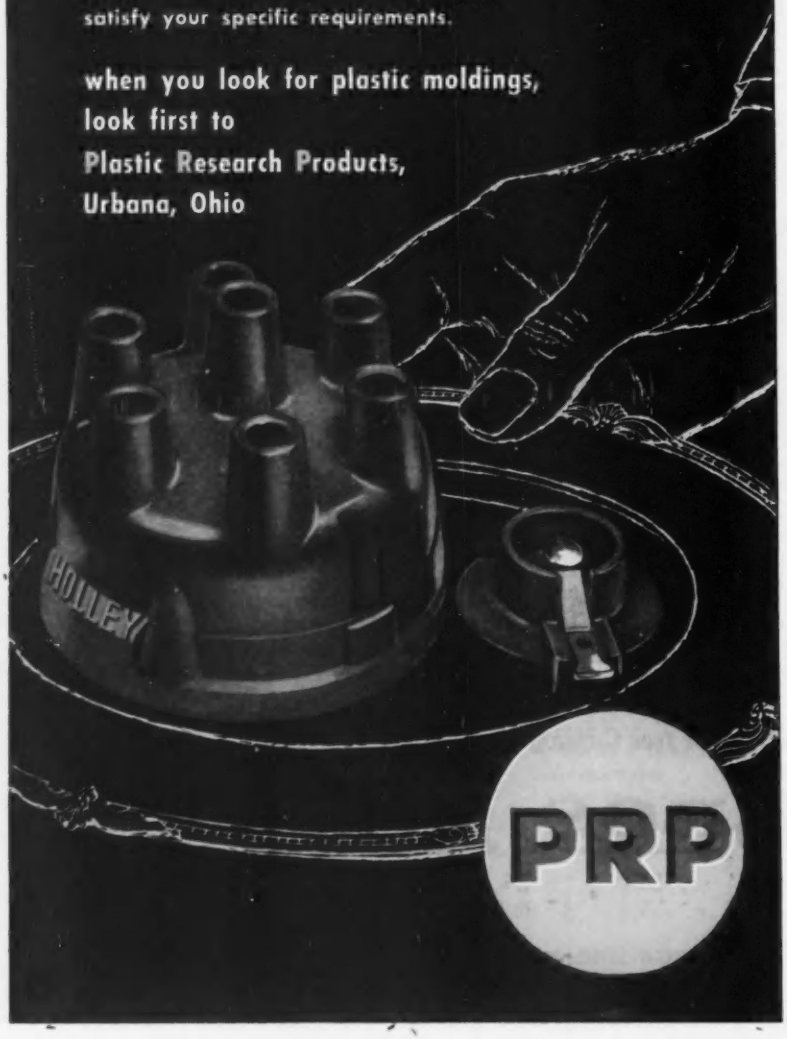

values of shear strength and coefficient of friction, and high values of the machining constant are desirable.

Surface Finish

Formerly, quality of the finished surface was rated entirely by simple visual inspection. Now however, with the adoption of a measurable unit—the microinch—by the use of a profilometer which can record the peaks and valleys of the surface, and with the aid of transparent plastic films by means of which complete, permanent visible records of all surface imperfections can be obtained, the nature of the surface can be defined and described much more accurately.

TABLE I

Type of Chip	Description of Chip	Surface Finish
1	Discontinuous—formed by machining of brittle materials	Good
1	Discontinuous—formed by machining of ductile materials at low speeds	Poor
2	Continuous—low friction between chip and tool face	Best
3	Continuous—high friction between chip and tool face	Worst

Table I summarizes the general relationship between the nature of the chip and the quality of the surface of the machined metal. The best finish is usually obtained with the continuous chip of low frictional resistance (type 2), and the worst finish generally results from the continuous chip of high frictional resistance (type 3).

Of the three basic mechanical variables, only the coefficient of friction is known to have an effect on the surface finish. A reduction in the value of this variable will be accompanied by an improvement in the surface.

Strain Hardenability

Another factor which has a great effect on the surface finish is the strain hardenability of the metal. A material which can undergo deformation and distortion without strain hardening is known as an ideal plastic. However, all engineering metals upon being internally sheared and deformed will strain harden, with the result that the chip and the region near the surface of the machined metal will be harder than the original material.

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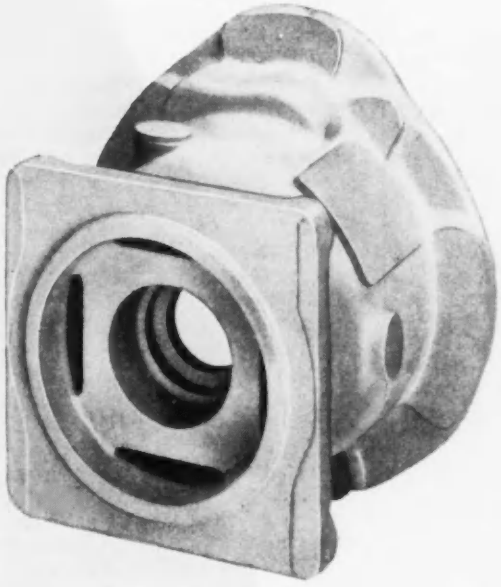

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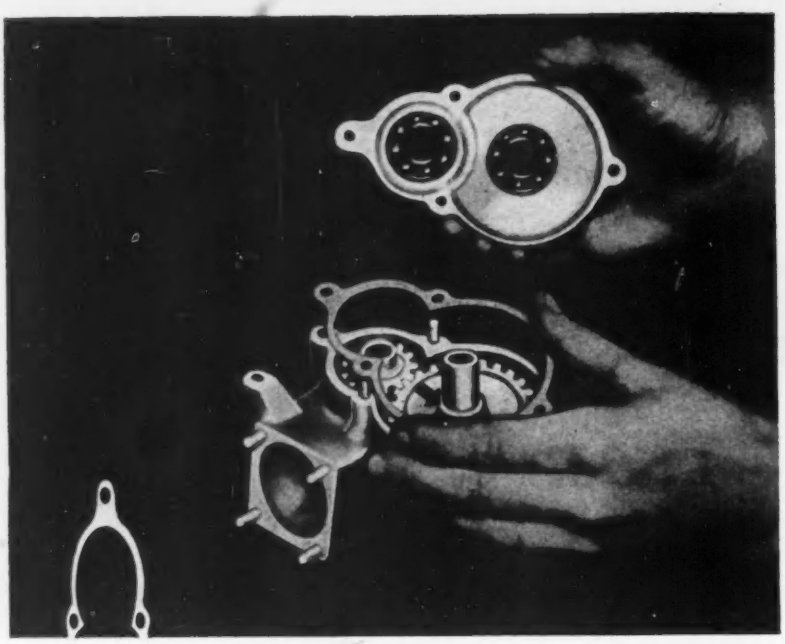

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costs are largely contingent upon the possibility of increasing tool life. From a practical standpoint this might be considered the most important of the factors which enter into machinability considerations. Life of a tool is usually measured in terms of the volume of metal removed before it must be reground, and it varies with cutting speeds and feeds, as well as with the nature of the metal being machined.

A cutting tool may fail (1) by breaking or chipping due to faulty design or application, (2) by wearing out or (3) by being overheated. The first of these is strictly mechanical in nature.

Tool Wear

Wear of a cutting tool occurs in two regions—on tool face or the area in contact with the chip and on the clearance side of the tool or in region where the tool is in contact with the finished surface. Wear at the tool face usually occurs some distance from the cutting edge and is known as "cratering." Wear on the clearance face begins at the cutting edge and is called a "wear land."

In general all tool wear may be attributed to two basic causes:

1. Wear due to the plowing or abrasive action of the carbides or other hard particles in the work piece.

2. Wear resulting from instantaneous welds that occur when the chip and finished surface slide over the tool faces.

Two types of weld may occur, namely, pressure welds and temperature welds. The former occur at temperatures below and the latter at temperatures above the recrystallization temperature of the metal. In the machining operation the chip formed is forced against the tool face under extremely high pressures, and if the cutting speeds and resulting temperatures at the chip-tool interface are low, pressure welds can be established. With a weld of this type, the weld interface is stronger than the two metals involved in its formation and when such welds are broken, the rupture occurs somewhere in the bulk of the chip, resulting in a transfer of metal from the chip to the tool face.

This is the "built-up-edge" which forms and breaks down hundreds of times per second and which eventually becomes part of the finished surface. As a result of strain hardening the built-up edge is much harder than the original metal and this in turn will cause acceleration in the rate of wear due to abrasive action. Abrasion due to the hardening of the chip, the

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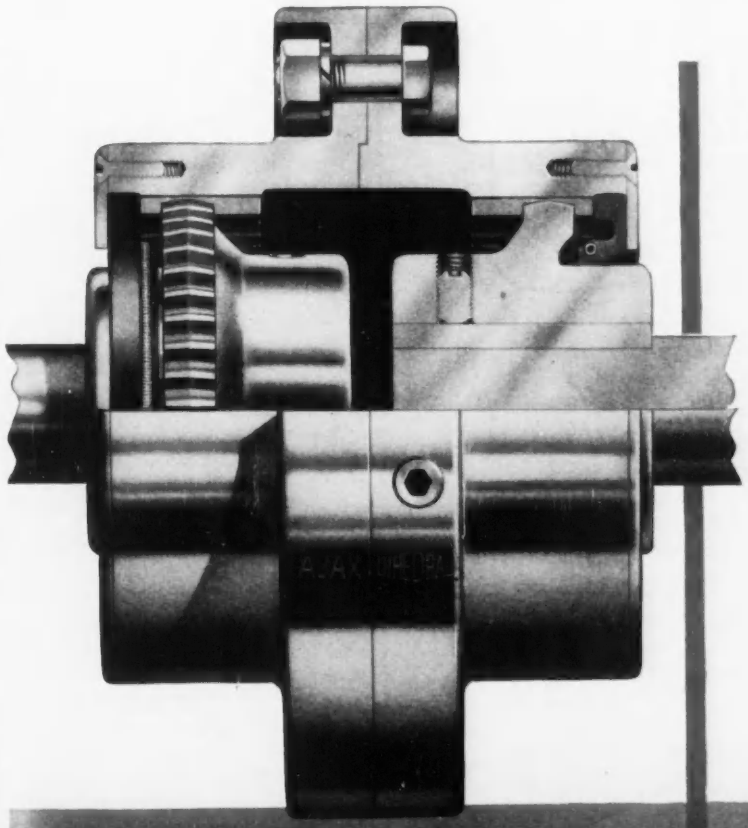

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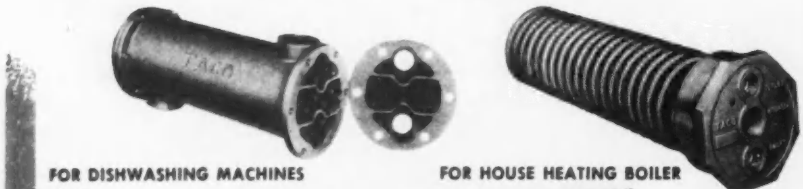

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built-up edge and the work surface depends upon the initial hardness of the metal, and the strain hardenability and the amount of shearing strain involved in the formation of the chip.

Formation of temperature welds occurs without strain hardening, and when the weld is broken, the surfaces separate in the same plane in which they were formed. There is no tendency toward the formation of a built-up edge, but when the surfaces separate, small particles of the tool matrix may be transferred to the chip. The extent of this transfer-type of wear will depend upon the mean area over which temperature welds occur and the relative strength of the tool and the work piece.

Thus, at very low cutting speeds, the temperatures will be low and the welds formed will all be of the pressure type. As the cutting speed is increased, temperatures will also increase and a point will be reached where temperature welds will begin to form. As cutting speeds are further increased, all the welds formed will be temperature welds.

Thus, the basic mechanical variables, whose effects on tool wear are known, are shear strength of the metal, coefficient of friction, machining constant, strain hardenability, initial hardness of the metal and microstructure of the metal.

Tool Life vs Temperature

Although the exact relationship between temperature, tool life and forces in metal cutting are far from being completely established, there seems to be a direct relationship between the temperature at the chip-tool interface and the tool life. As this temperature increases, ability of the tool to withstand the forces exerted upon it decreases rapidly. Consequently, in the interest of long tool life, it is imperative that temperature at the chip-tool interface be kept as low as possible.

Metallurgical Facts

Until recently little has been done to apply metallurgical knowledge to the improvement of machining conditions. However, it is now recognized that tool life and surface finish are directly related to the microstructure of the metal being machined.

Materials having similar metallurgical structures will likewise have similar machining characteristics, regardless of their relative physical and chemical properties. On the other hand, it has been shown that slight variations in the microstructure within a single piece of stock can cause as much as a five-fold change in tool life.

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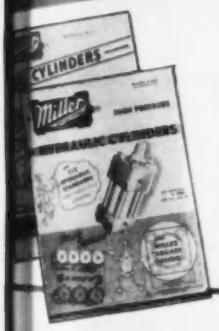

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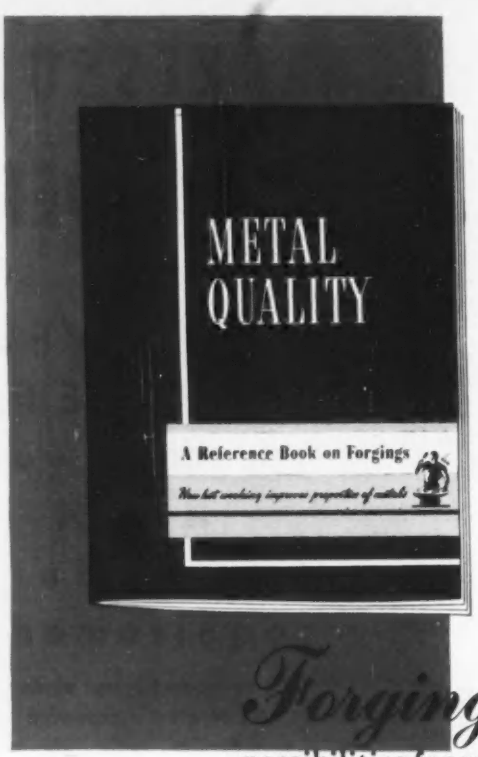

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OUR READERS SAY

Fine Pitch Drawing Data

To the Editor:

I read with interest the article "Fine Pitch Drawing Data Required to Assure Quality" in the July 1952 issue of PRODUCT ENGINEERING.

On page 176, the author states that a "composite check comes closest to the truly functional check." It can be shown that a sinusoidal distribution of tooth spacing error, such as would be caused by the indexing mechanism in a gear cutting machine, is practically indiscernible on a variable center distance check. To complicate matters the effect of tooth spacing error in high precision gearing is usually greater than the effect of runout. Thousands upon thousands of tests on fine pitch instrument gears have proved that there is very little correlation between a composite check and the transmission of uniform angular motion.

On page 177, the author mentions that "the effect of runout on the transmission of uniform angular motion is inversely proportional to the diameter of a gear." This is true only for driven gears. The angular error caused by an eccentric driver is entirely independent of the driver gear diameter. An ASME paper on gear eccentricity (#51-F-36) points out that the angular error caused by an eccentric driver is inversely proportional to the base circle of the driven gear.

In the last paragraph of the article the author mentions that undercutting of the involute takes place at 32 teeth in the 14½ deg. system and at 17 teeth in the 20 deg. system. These values have been stated by many authors but, with standard fine pitch finishing hobs, it can be shown that undercutting takes place at approximately 41 and 23 teeth in the 14½ deg and 20 deg systems, respectively.

—RICHARD L. THOEN

To the Editor:

This is in reply to the comments of Mr. Richard L. Thoen regarding the article titled, "Fine Pitch Drawing Data Required to Assure Quality," in the July issue of PRODUCT ENGINEERING under my "by-line."

In an article covering a wide range of subjects, it is difficult to go into hair splitting details due to space limi-

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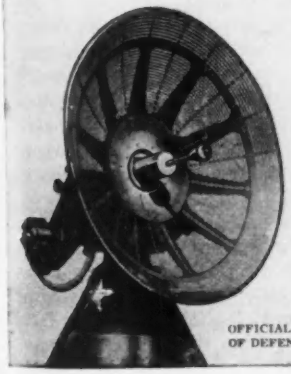

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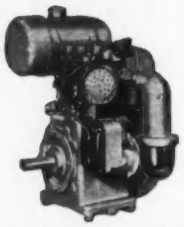

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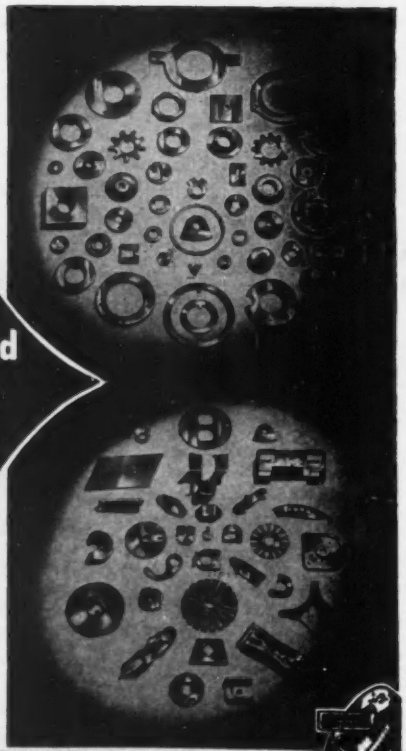

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tations. One can say too little or not enough. It is quite understandable why discerning readers might question apparent dogmatic statements, any of which might well become the subject of a separate article.

The author is grateful to Mr. Thoen for the opportunity of expatiating on the points he has raised. We do not differ on essential points, but rather, if we differ at all, on minor details.

Regarding the subject of undercutting of gear teeth, the author agrees with Mr. Thoen that the common concept that undercut in gears of 14½ deg pressure angle starts at 32 teeth and those of 20 deg pressure angle at 17 teeth is not entirely correct. It depends entirely on what is meant by undercut, and what particular tooth form system we are talking about.

Undercut, as defined by the American Standard Gear Nomenclature A.G.M.A. 112.02, A.S.A. B6.10-1950, is as follows:

> A condition in generated gear teeth when any part of the fillet curve lies inside of a line drawn tangent to the working profile at its lowest point. Undercut may be deliberately introduced to facilitate finishing operation.

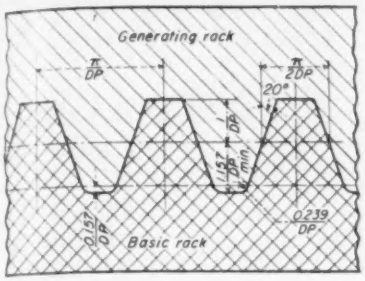
This statement implies that all gears are undercut to some extent. It further explains that undercut, for some purposes is introduced deliberately.

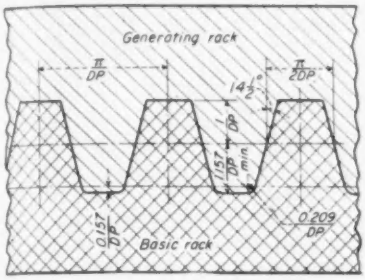
The question is whether some undercut is or is not objectionable.

The Fine-Pitch 20 deg Involute System A.S.A. B6.7-1950 states, "that in order to avoid objectionable undercut, pinions with 17 teeth and fewer are enlarged." In this system, undercut starts, in most cases, at the working depth. The reason all undercut was not eliminated is due to the fact that inadequate top lands would result in pinions having addendums equal to 1/N. They would therefore require stubbing. The gain in profile length at the base of the teeth by avoiding all undercut would be offset by the amount chopped off the tips to obtain a practical top land.

Undercut in pinions varies with: (a) the choice of tooth form system; (b) the top land of the generating tool; (c) the type of generating tool used, (whether a hob or gear shaper cutter); (d) whether the generating tool has an edge fillet or is razor sharp, and; (e) the depth of the cut.

Undercutting of pinions of 14½ deg and 20 deg pressure angle is thoroughly covered in Prof. Buckingham's book "Spur Gears." The accompanying Figs. 1 and 2 show the basic rack for two systems of generated gears. Pinions cut to nominal dimensions





according to these systems are undercut.

Undercut in 14½ deg pinions begins at approximately 31 teeth and in 20 deg pinions at 17 teeth, respectively, as shown by Table V and VII, pages 114 and 124 of Buckingham's book. Most of us have these two systems in mind when talking about undercut pinions. This concept, is wrong because it does not take into account all the many ramifications of undercut.

Regarding Mr. Thoen's comments on the influence of eccentricity, the author finds himself in perfect agreement with statements on the subject in the A.S.M.E. paper. In the article in question, it was stated that the effect of runout on the transmission of uniform motion is inversely proportional to the diameter of a gear. No mention was made of driver and driven to avoid a lengthy discussion. The idea was to focus the attention of the designer on things of primary importance.

In regard to the value of the composite check and its approach to a truly functional check, the author finds himself at some variance with Mr. Thoen. While it is not claimed that a blind composite check is of much value in determining absolute tooth spacing errors, there is a preponderance of evidence that a composite check which records the radial displacements on a chart can be used as a qualitative (not quantitative) yard stick for angular transmission. Such a check to be of value must be made on an instrument that charts the radial displacements. The instrument must have these features: (a) sensitivity; (b) repeatability; (c) em-

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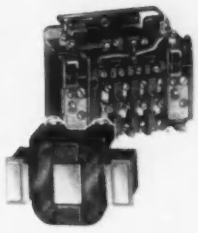

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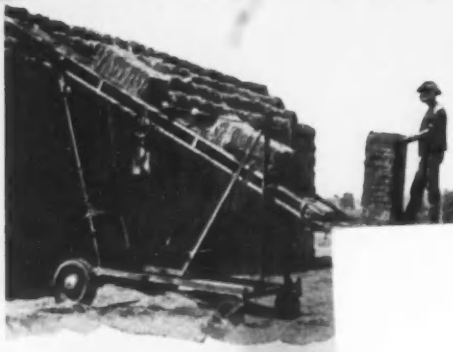

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ploy a checking element of a high order of accuracy; and (d) be able to record minute radial displacements at magnifications such as 400 times size.

It was found by comparing many traces of gears which showed the radial displacements with curves of integrated spacing checks, (made by engaging a gear to be checked with another stationary gear or rack and measuring the angular deviations of successively engaging teeth, angular errors being integrated over the arc of action), that a qualitative common denominator can be found.

There are a number of means of obtaining a composite check of gear teeth, some of which are quite archaic. When the right equipment and techniques are employed, remarkable correlation can be established. The difference between the older and newer methods is comparable to using a common stethoscope to make an audible check of heart beats, and using a cardiograph for analyzing heart trouble. One instrument can be used only to make a rough guess, while the other permits a scientific analysis. A composite check was made of a gear at four hundred magnification. On the same chart is a trace of an integrated spacing check made of the same gear using a Vinco dividing head. In this check, the gear was engaged with a master rack and successively rotated in tooth increments. Intimate contact was retained between gear and rack in such a manner that when the exact angular increment was measured on the dividing head the error was read in terms of equivalent radial displacement of the gear with the rack, thus establishing a common denominator.

The proof of the fact that a properly made composite check can be used to control the quality of instrument gearing where uniform motion is essential, is found in the hundreds of thousands of such gears that are now being manufactured and checked on recording type composite checking equipment.

It is refreshing to find a discerning reader who takes the trouble to make constructive comments on an article. The true reward of authors is measured by the interest taken by readers like Mr. Thoen. —L. D. MARTIN
Gear Engineer
Eastman Kodak Co.

Nomogram Data Not Experimental

To the Editor:

With regard to my article, "Stress Charts for Pressurized Elliptical and Oblong Tubes," which was published

"Joe, getting small metal parts with precision tolerances is always a problem."

"Not when we have Torrington make them, Tom. Their production methods and facilities are among the finest in the world."

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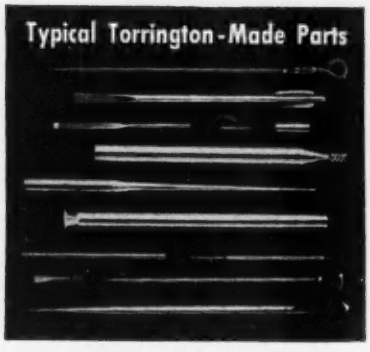

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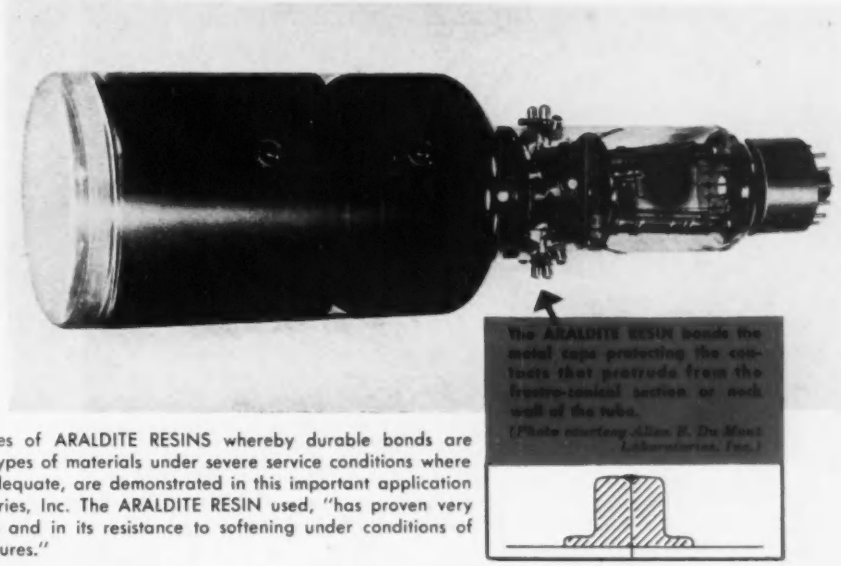

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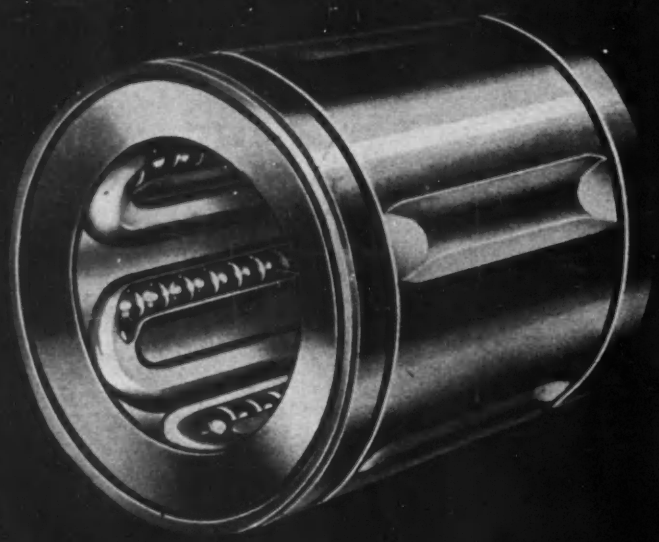

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in the June 1952 issue of PRODUCT ENGINEERING, I wish to call your attention to several errors I have found in the printing of the article.

1. The Nomogram and graph are not based on experimental data from photelastic models, as is stated. They are the result of a rational mathematical solution of the problem. The derived formulas are complex and tedious to solve for a specific case; therefore the nomogram and chart were constructed to represent these formulas and give rapid, easy solutions. Many photoelastic tests on models were performed to prove the validity of the developed theoretical equations.

2. In the list of symbolism, $\frac{ab}{t}$ should be $\frac{\sqrt{ab}}{t}$.

3. For the Oblong Tube Stress Chart on page 199, the position of the letters B and C on the tube cross-section should be reversed. Location B should be on the inner surface of the long-axis, and location C should be on the outer surface of the short axis. —J. C. WEYDERT

Magnetized Steel Stampings

To the Editor:

First, I would like to comment on the item "Magnetized Steel Stampings," which appeared in "Our Readers Say" column of August 1952.

While I find your answer quite good, I would like to point out a further possibility which may lead to magnetized steel stampings.

If a die has been ground on a magnetic chuck or plate and has not been properly demagnetized, it could very well induce magnetism in small stampings; and a punch stroke or stamping would help to orientate the molecules in the same polarity as the die. I have seen a spring steel wire passing through a rapidly revolving spindle for straightening became magnetized. Upon investigating it was found that the straightner spindle was magnetized. This spindle had just been made and ground. We passed it through a demagnetizer; and the wire after being cut in short lengths showed no further signs of magnetization.

Now I have a problem on which I would like some enlightenment. It is in regard to winding a plastic film on a cardboard core. The width of the film may be anything from say 5 inches to 15 inches, according to various runs. The core diameter is 3 inches, and final roll size is about 10 inches. In order to avoid starring at the core, should the roll be wound at (i) constant tension

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WRITE FOR CATALOG

Our Readers Say.....continued

(ii) constant torque or (iii) something in between, depending on the material being wound?

It seems to me that constant tension is not the answer. If we consider the film tension, when the film is wound, as hoop stress, the total radial force will increase with the diameter of the roll. And whereas at the beginning of the roll we have a fairly rigid core, as the roll increases in diameter the effective core to the last loop is a great deal more pliable; so that we have the least resistance where we need it most.

Has any article been published in the past, in Product Engineering on this subject? If so, I would like very much to read it. —J. PAUL BERGEVIN
Shawinigan Falls, Quebec

Ed—To avoid starring or crazing at the core, I would think that the properties of the material being wound would have a direct bearing on allowable core diameter, and secondly, with a constant torque, the film tension would decrease, as would the hoop stress, as the diameter of the material builds up.

In answer to your second question, Product Engineering has not published an article on this subject.

Latest in Level Indicator Design

To the Editor:

In your June 1952 issue you ran an article on a optical high level switch. Heck, we've got that licked hollow! The Tektor is a capacity switch that operates on the approach of anything and, requires only a single tube, with nothing else to operate it.

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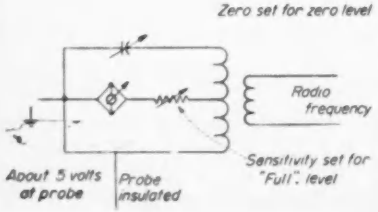
I'm all out of circulars on the LF 2, but below is a brief sketch of the cir-



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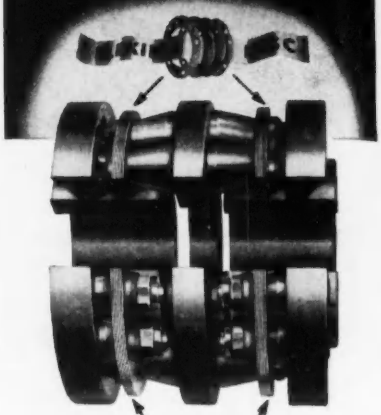

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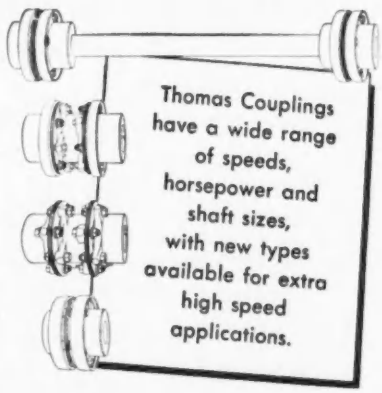

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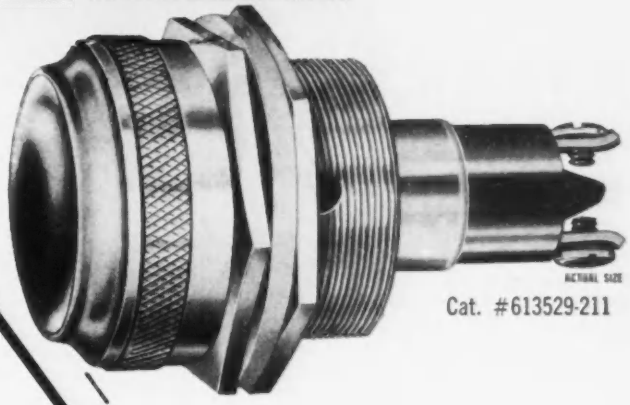

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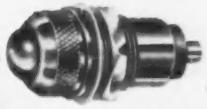

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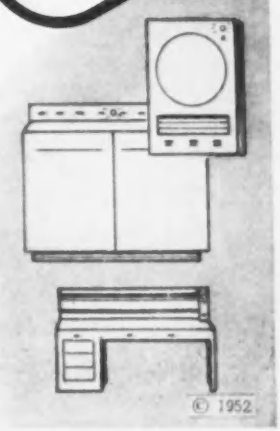

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cuit principle which will give you the idea. Basically, we put an insulated probe down the center of a tank. Then we know that this probe has some capacity to ground. When we put material, solid, liquid, what have you, near the probe, it changes its capacity to ground. Calibrate that change to read height and there it is. Simple when you know how: Oh, yes, the data can be telemetered, too, if desired. OK, it's your turn now. What do you think of this gimmick?

Incidentally, Sans Souci is a highly interesting and readable department. Encourage the lad who writes it. Give him a raise, as he deserves it! Or is he under your wage stabilization scheme? Anyway, he is good.

Finally, am interested in the AEG recorder mentioned on page 191 of the August issue of PE., name and address of firm, and if possible, to whom to write. —HARRY H. SCHWARTZ
Electrodesign Co.
Montreal, Canada

Ed—Your appreciation of Sans Souci is well received. I am considering giving myself a raise. Regarding your last paragraph, there are two addresses for the firm making the AEG recorder: Allgemeine Elecktrizitats-Gesellschaft, Berlin-Grunewald, Germany; or A.E.G.—Buro Frankfurt; Mainzer Landstrasse 23; Frankfurt/Main, Germany.

Error In Design Work Sheets

To the Editor:

Regarding the nomogram and text on Torsion Spring Design by Carl P. Nachod of pages 134-5 of PRODUCT ENGINEERING Design Works Sheets (10th Series), I believe equation (3) to be in error. This error, carried through to the chart, reduces values of stress thereby obtained by a factor of 10.

The derivation of equation (3) usually takes the following form:

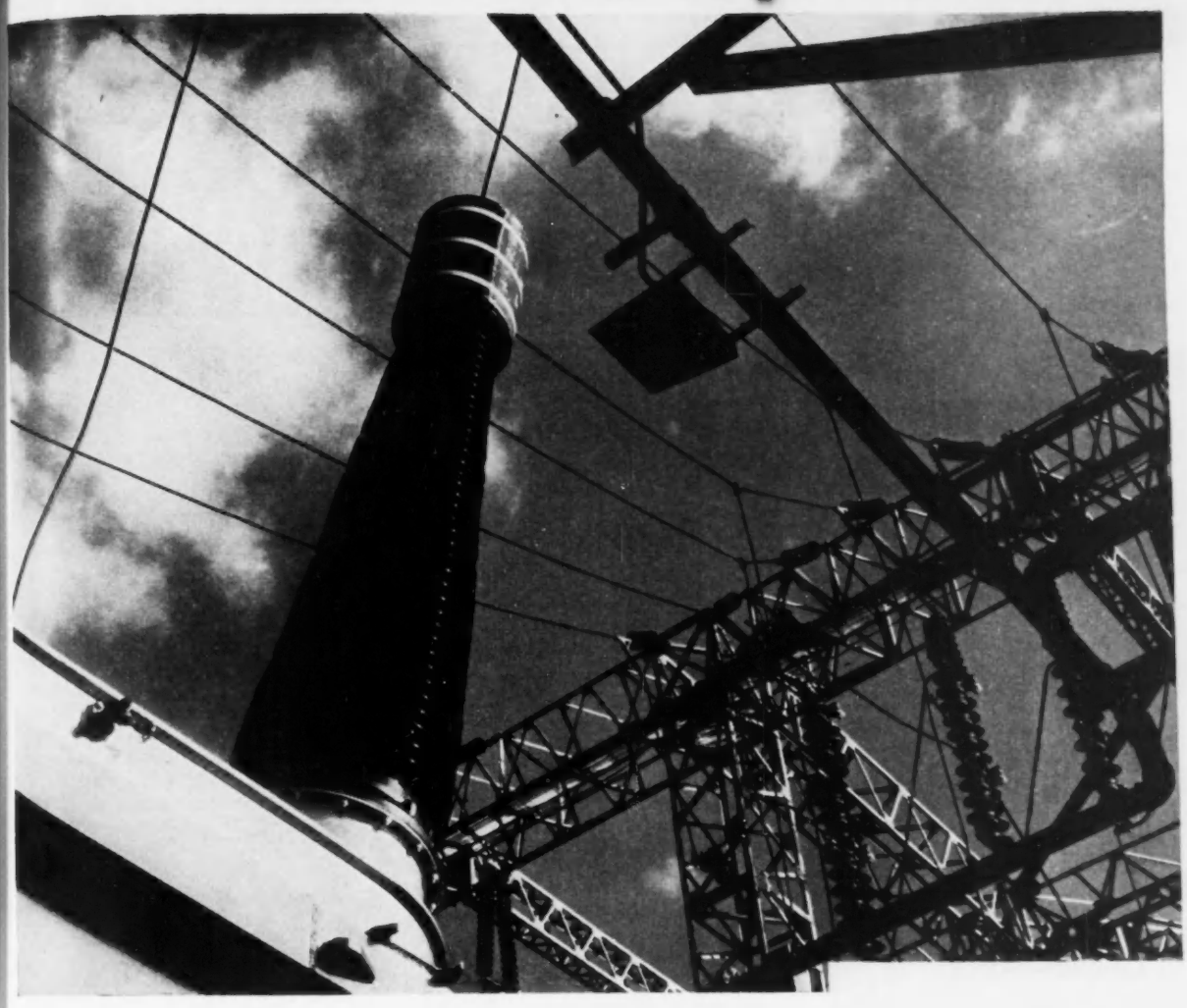
$$(A)\quad S = \frac{MC}{I}$$

S – Stress
M – Moment
C – distance from natural axis to outermost fiber
I – moment of inertia about neutral axis.

In Mr. Nachod's article "M" is replaced by "T." Since the moment "T" is equal to load X distance, the following holds true:

$$(B)\quad T = PR$$

For a round wire section, "C" would



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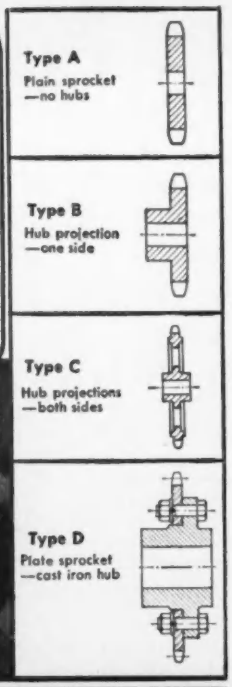

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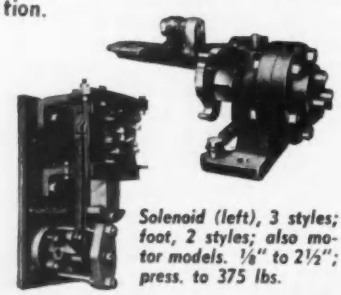

Solenoid (left), 3 styles; foot, 2 styles; also motor models. ⅛" to 2½"; press. to 375 lbs.

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be equal to $\frac{d}{2}$ where d equals the diameter of the wire. Also, "I" equals $\frac{\pi d^4}{64}$.

Substituting (B) in (A), we then have:

$$S = \frac{TC}{I} = \frac{T\,(d/2)}{\frac{\pi d^4}{64}} = \frac{32T}{\pi d^3}$$

Simplifying this, we get:

$$S = \frac{32T}{3.14d^3} = \frac{10.2T}{d^3}$$

You will note, therefore, that the error in Mr. Nachod's formula has to do with the decimal point, since he specifies 1.02 as the constant rather than 10.2.

The final formula in the write-up includes the constant "c". This constant is a correction factor which, as Mr. Nachod mentions, will vary from 1.23 to 1.05 depending entirely upon "r". This factor had been determined experimentally and is similar to a correction factor used in the design of rectangular section springs. It affects the overall results only very slightly.

JOE FRADKIN
Reeves Instrument Corp.

Ed—We stand corrected.

ERRATA

July 1952, page 121. *Selecting Motor-Mounted Magnetic Brakes.* Top of first column—"exceeds four to six per hour" should read "four to six per minute." Page 123, middle of third column—"removal of brake power" should read "removal of motor power."

July 1952, page 175. *Fine-Pitch Gear Drawing Data Required to Assure Quality.* Bottom of first column—"0.09945" should read "0.9945."

August 1952, page 159. *Converting Decimal Fractions to Actual Gear Rates.* Equation (13) should read $a(b+d) - b(a+c) = -v$. Right hand column, second fraction should be 0.528302.

September 1952, gatefold opposite page 182, *High Speed Photography in Design.* Color code at top should be reversed. Opposite black line it should read, "Optical components optional in the type of camera illustrated;" opposite red line it should read, "Optical components essential in the type of camera illustrated."

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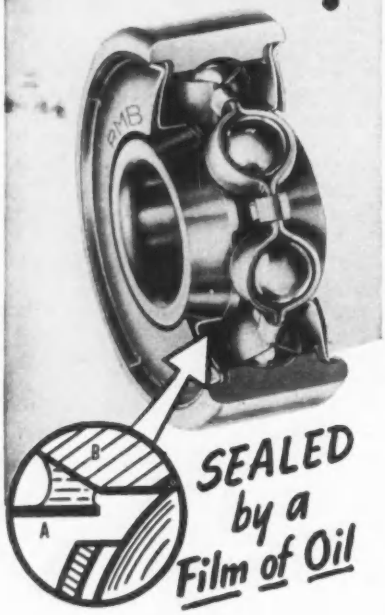

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J. RALEIGH NELSON, *Prof. Emeritus of English, College of Engineering, University of Michigan.* 356 *pp,* 6 x 9 *in. Published by McGraw-Hill Book Co., 330 West 42 St., New York 36, N. Y.,* $4.50.

The subject is divided into five parts. First, design and composition of the report are considered. Next, the author gives specific directions for the setup of both long and short form reports. These are illustrated by several sample reports annotated for study. The third part of the book outlines a systematic procedure for the critical examination of a report, with a number of clinical studies of typical cases. The fourth, which is a summary of the fundamentals treated in the three preceding sections, serves as a ready reference for both instructor and student. The fifth part presents a 16-week course in report writing which can be used as a basis for classroom purposes or as a guide for study for those in practice who wish to enlarge and clarify their appreciation of the fundamentals of report writing.

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ADAM ABRUZZI, *Ass't. Prof. Stevens Institute of Technology,* 290 *pp,* 6½ x 9 *in. Published by Columbia University Press, Morningside Heights, N. Y.,* $6.

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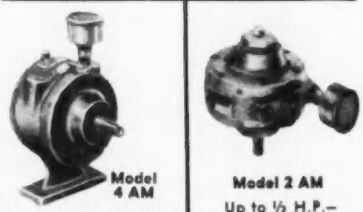

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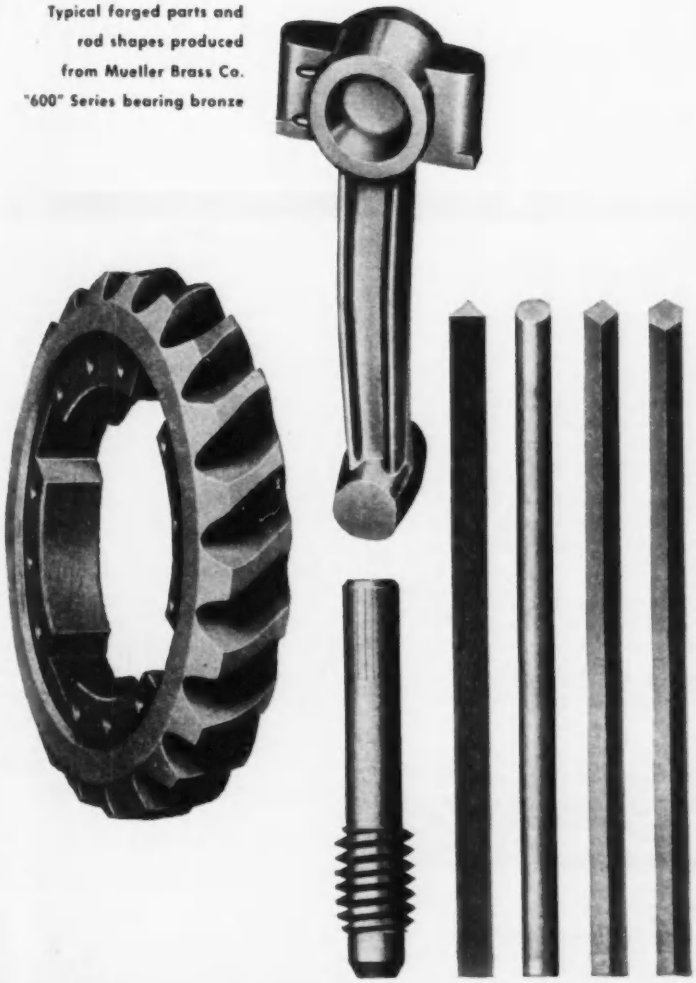

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also shows how precise estimates and predictions can be made about the production rates of workers and operations, and how to develop production standards known to be attainable by the workers.

Some of the more detailed conclusions developed are: (a) the consistency of work performance depends on the length of operation cycle and not on the skill of operator; (b) the workers with the greatest output are not those who work fastest, but those with fewer and shorter delays and interruptions; (c) the motion patterns of individual workers do not remain constant even for a limited period of time.

The book presents a complete methodology for handling the problems of work measurement. The opening chapters analyze present ways of investigating these problems. Here Dr. Abruzzi points out that many so-called "scientific procedures are intimately associated with collective bargaining and that, consequently, labor and management have interpreted and used the results to advance their own interests. Dr. Abruzzi then explains his own objective procedures using experimental data on industrial operations. In these experiments, liberal use is made of statistical quality control and other statistical techniques which have proved so successful in product quality work. The book contains 25 figures and 55 tables. The examples are presented so that industrial engineers can apply the same principles and procedures to the work-measurement problems in their own plants and industries.

Practical Mathematics

CLAUDE I. PALMER *and* SAMUEL F. BIBB, *Assoc. Prof. of Mathematics, Ill. Institute of Technology,* 769 *pp.* 5½ x 8¼ *in. Published by McGraw-Hill Book Co.,* 330 *West* 42 *St., New York,* 36, *N. Y.,* $4.50.

This new fourth edition of this one volume contains the essentials of the four separate books (practical Mathematics, Parts I to IV) by the authors. It contains new material suggested by students and teachers, and new problems that broaden its scope. Presentation has been simplified and explanations have been expanded. More sample problems are solved and more hints for solving problems are given. Some new illustrations are included, and others have been redrawn.

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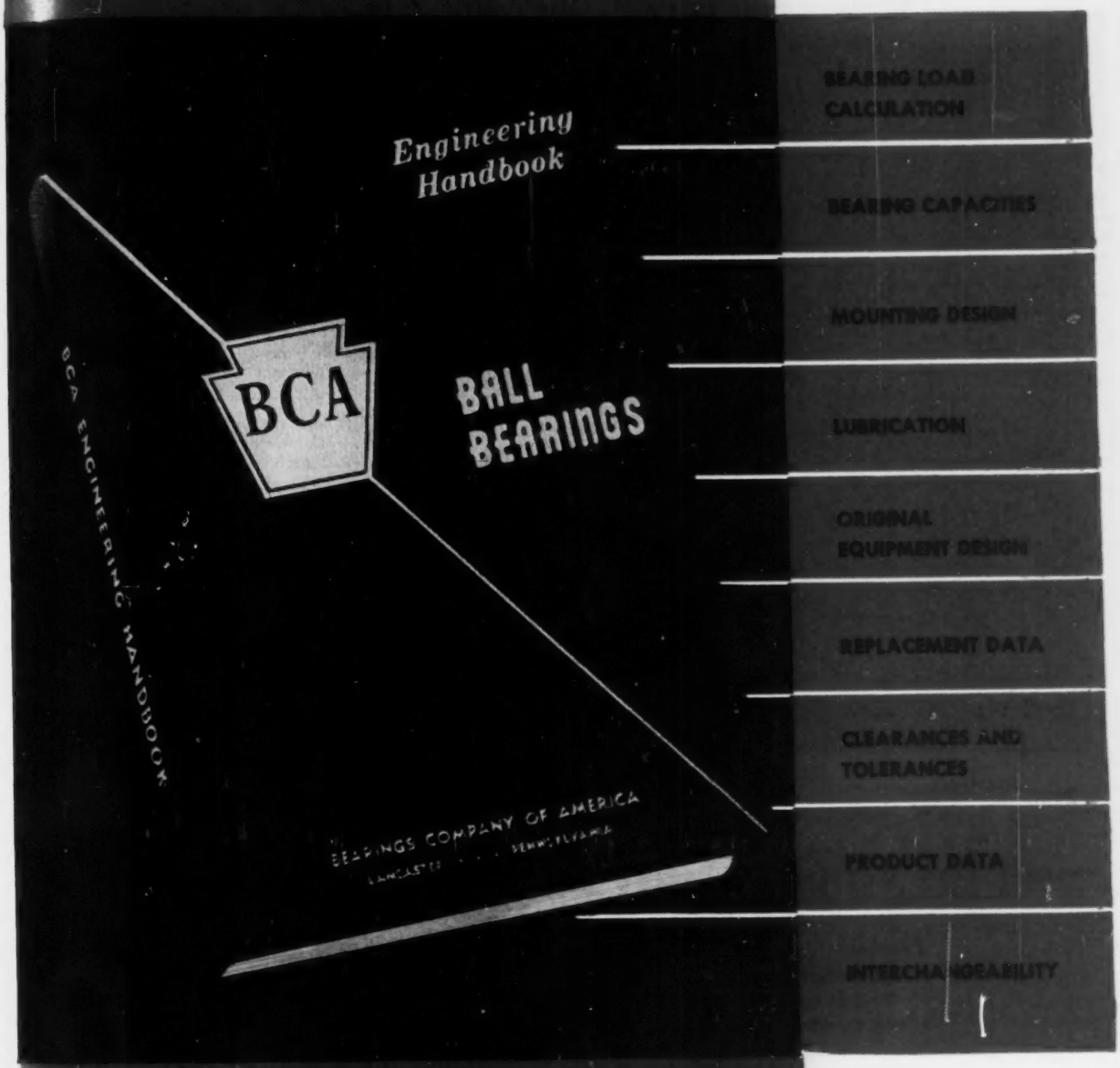

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Rigid Frame Formulas

A. KLEINLOGEL, 460 *pp*, 6½ x 9½ *in. Published by Frederick Ungar Publishing Co., 105 East 24 St., New York 10, N. Y.*, $10.

This, the first American edition of the eleventh edition of the German "Rahmenformeln," includes all single-span types of rigid frames.

Because of its pictorial character, this book is, in a sense, unique. The contents consists of sketches of the 114 different frames for which shear and bending moment equations and diagrams are presented in the main text. The reproduction of the large numbers of diagrams has made it necessary to retain the original notation, which differs somewhat from that commonly used by American engineers. These include the use of J instead of I for the moment of inertia, F instead of A for cross-sectional area and sign conventions. However, these are adequately defined in the text and should present no handicaps to those familiar with the subject.

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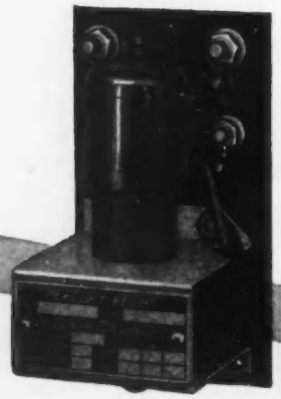

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loading conditions, may be used to secure results rapidly by the direct substitution of numerical values. Designers, even without advanced training in structural analysis, can avail themselves of the advantages of the rigid frame, by its direct use and with but little added effort, influence lines, or tables, can be readily constructed as described in detail in the text.

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Third, the rigid frames, themselves statically indeterminate, can be used as units in adopting a "primary structure" dealing with cases of more highly indeterminate frames, and so bring such structures within the range of easy computation by means of the Maxwell-Mohr work equation or, if one prefers, the slope-deflection equations. This extends considerably the field of practical application in the design of such structures and makes available an accurate and rapid method of analysis of structures which could heretofore be handled only by approximate methods or by lengthy numerical computations.

Hardy Cross: Engineers and Ivory Towers

Edited and arranged by ROBERT C. GOODPASTURE, 141 *pp*, 6 x 9 *in. Published by McGraw-Hill Book Company, 330 West 42nd St., New York 36, New York.* $3.75.

During 30 years as college professor and engineer, Hardy Cross developed a philosophy which he tried to disseminate to young men who were entering the profession of engineering. While his contemporaries may know him best for the "Hardy Cross System" of analysis, his students remember him for his lectures on the professional aspects of engineering. This books presents in essay form a few of the more memorable of these.

In his thinking Cross continually stresses that engineering is an art as well as a science, and as such it should not be shackled too tightly with rigid rules, formulas and standardization. In engineering there is no standardization unless there is well founded reason for it.

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tion; that there can be much fredom with regulation; that the regulation is bad only if it destroys the originality; and the originality unchecked would best be checked by some regimentation.

Another point that Cross strives to make is that the layman does not understand the engineer: what he does or how he does it. In the popular concept, the engineer is guided by facts supplied by scientists and his conclusions are based purely on physical facts. Actually the engineer takes scientific facts and forms them into an end product through imagination and creative thought with the help of additional data from both the social and the physical sciences.

This misconception has given birth to a group who profess to be engineers. Masquerading under a title composed of an adjective and the word engineer, such as "humanity engineer," social engineer" or "economic engineer," they attempt to give the impression that they deal with measurable data from which definite laws can be deduced. But they differ from engineers in that they usually do not know what they are doing and they scorn the important details.

In "Engineers and Ivory Towers," Hardy Cross has taken engineering out of the popular concept associated with graphs and formulas and lifted it into its rightful place.

Handbook of Applied Hydraulics, Second Edition

Editor-in-Chief, CALVIN VICTOR DAVIS, *Vice-President, Harza Engineering Co., 272 pp, 6½ x 9¼ in. Published by McGraw-Hill Book Co., 330 West 42 St., New York 36, N. Y., $15.*

The objectives of this second edition are identical to those of the first. It deals primarily with the practical aspects of all phases of hydraulic engineering and includes a wealth of reference material.

In response to requests during the last ten years, new sections have been added on water hammer, surge tanks, speed regulation and navigation locks. Other sections either have been rewritten or brought up to date. The basic policy of drawing illustrative examples from the design files of actual projects has been followed throughout. Reference material on hydraulics has been presented as an appendix and a second appendix covers the graphical analysis of many of the problems presented.

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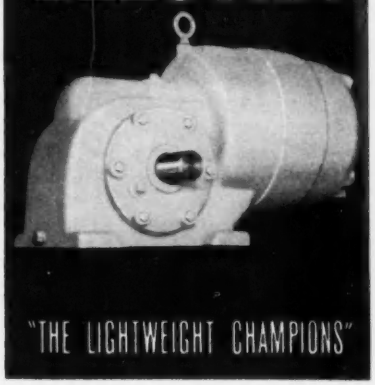

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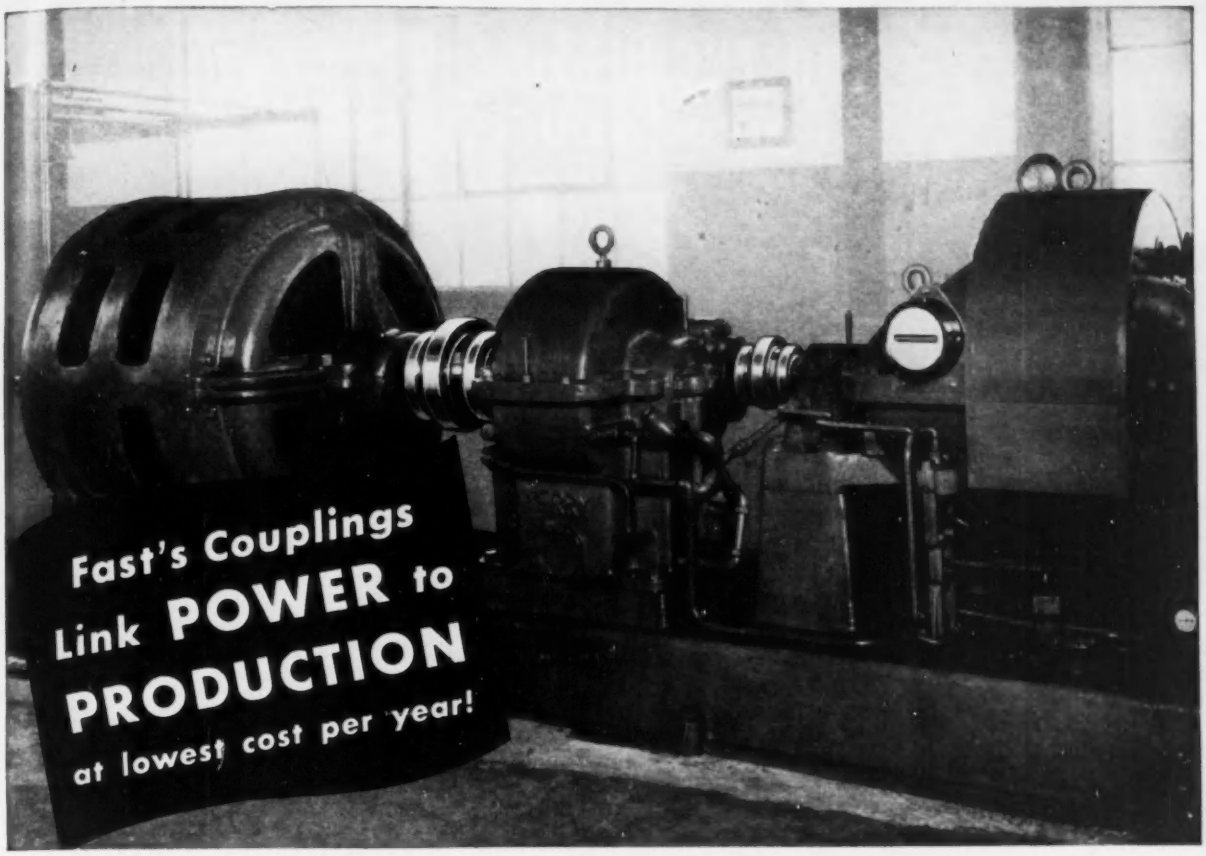

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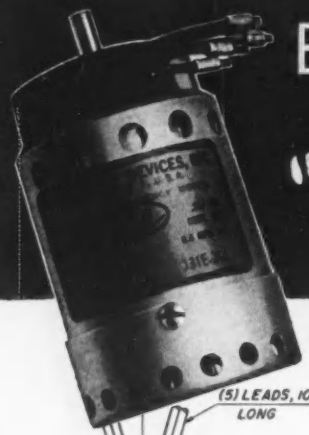

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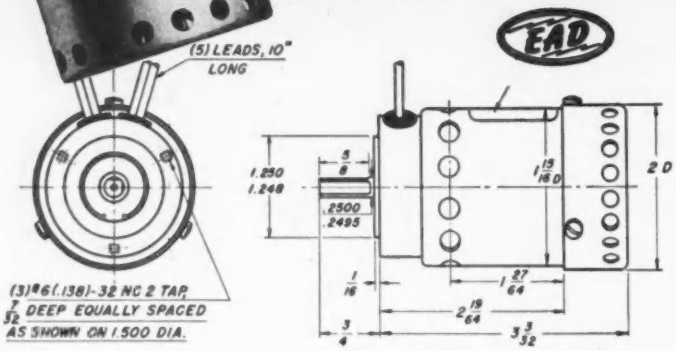

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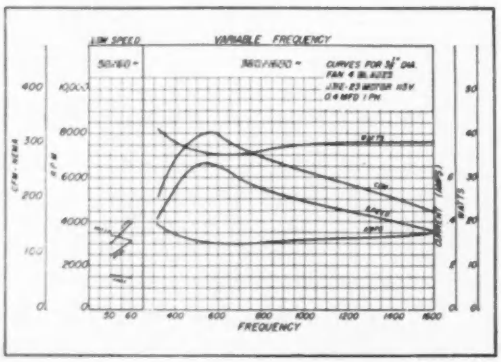

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Mechanics, Part I, Statics

J. L. MERIAM, *Associate Professor of Engineering Design, University of California,* 340 *pp,* 6 x 9 *in. Published by John Wiley & Sons, Inc.,* 440 *Fourth Ave., New York* 16, *N. Y.,* $4.

This, the first of two volumes covering basic engineering mechanics, integrates the usual pre-engineering background of physics, mathematics, and graphics. The author progresses in easy stages, from fundamentals to advanced theory, always emphasizing the importance of principles and problems which apply to them.

The first chapter presents a summary of the foundations of mechanics. The second and third present the development of the resultants of force systems and the equilibrium of force systems with a minimum of attention to special cases.

Chapter six covers the equilibrium of statically determinate beams. No analysis of the distribution of force over the beam cross-section is made since this more properly belongs to strength of materials.

Chapter eight covers the principles of virtual work and shows the type of problem for which this method is superior to the equilibrium method based on force and moment summation.

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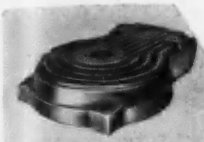
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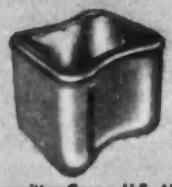
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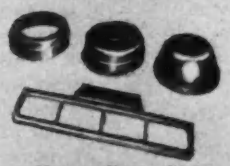
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mass are treated in the first appendix. Appendix B consists of a collection of useful tables. The collection of problems used to supplement and illustrate the text is impressive and almost entirely original.

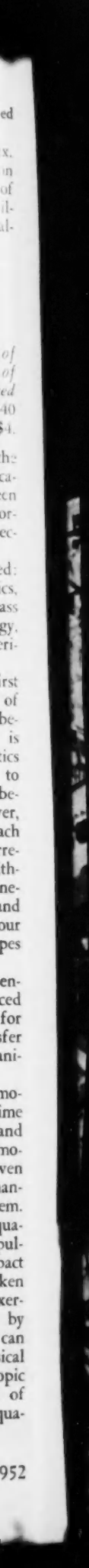
Mechanics, Part II, Dynamics

J. L. MERIAM, *Associate Professor of Engineering Design, University of California, 330 pp, 6 x 9 in. Published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y., $4.*

"Dynamics," the second part of the treatment of the theory and application of Mechanics, has already been lauded for its careful and logical organization plus its outstanding collection of problems.

The seven chapters are headed: Principles of Mechanics, Kinematics, Principles of Kinetics, Force, Mass and Acceleration, Work and Energy, Impulse and Momentum, and Periodic Motion.

Chapter I is a repeat of the First Chapter of Part I, and a review of this introduction is recommended before the more advanced material is considered. The subject of kinematics has been separated from kinetics to make possible a clear distinction between these two elements. However, if desired, the kinematics of each motion can be followed by the corresponding kinetics of that motion without difficulty since the chapter on kinematics and the one on force, mass and acceleration are each divided into four similar parts describing the same types of motion.

In the discussion of work and energy, considerable emphasis is placed on the energy equation and its use for a conservative system. The transfer between mechanical and non-mechanical energies is also discussed.

The chapter on impulse and momentum leads directly into the time rate of change of both linear and angular momenta. Equations of motion with variable mass are given special emphasis and divided in a manner which should clarify this problem. Application of the variable mass equations to modern aspects of jet propulsion is made. The subject of impact is described briefly with account taken of the energies involved. Care is exercised not to mislead the reader by implying that problems of impact can be adequately described by the classical "coefficient of restitution." Gyroscopic motion is described with the aid of the general impulse-momentum equation which is then simplified.